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EXPERIMENTS IN TELEVISION OVER TELEPHONE CABLE FACILITIES *

BY

C. R. KRAUS [1]

INTRODUCTION

When as in silks my Julia goes,
Then, then methinks how sweetly flows
The liquefaction of her clothes.

Now as I cast my eyes and see
That sweet vibration each way free;
Ah! How that glittering taketh me.

Robert Herrick

Robert Herrick could not have known that the picture these beautiful lines transmit to the mind's eye would, 300 years after their composition, serve as a standard for the complicated medium of television. But now the stages of television are filled with gentle Julias. They smile, frown, flirt, nod, and they go rippling in their silks. And we demand of those little screens in our living rooms that they should not cause us to miss the slightest nuance of Julia's expressions or movement. We must see the twinkle in Julia's eye, the arch of her brow, the pout of her lips, the strands of her flowing hair and the rippling of her silks.

In the very early days of television the results were far from that. The picture permitted fairly certain judgment that the figure on the screen was Julia and not King Lear, but twinkling eyes and rippling silks—definitely not. However, improvement followed improvement, and in 1941 the present 525 line picture was standardized with results that you all know. It was found, however, that the bringing of Julia's

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[1] General Staff Transmission Engineer, The Bell Telephone Company of Pennsylvania, Philadelphia, Pa.

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rippling silks into our living rooms required carefully coordinated systems engineering. The transmission of increased picture detail at 30 pictures per second requires what is known technically as increased frequency bandwidth. To set a bench mark that you are familiar with, the transmission of your voice also requires bandwidth, about 2700 cycles. Let us call this a voice channel. We could transmit pictures over a voice channel at 30 per second but the detail would be so limited that Julia and King Lear would look about the same. In order to be sure which of two figures is Julia and which King Lear, some 40,000 cycles would be required. Note that 40,000 cycles is equivalent to more than ten voice channels, just for enough detail to distinguish two figures; you see an important cost factor entering. Now to get back to that ripple. In order to show it with all its allure it is necessary to take full advantage of the 525-line broadcast standard, and that means 4,000,000 cycles or more than 1000 voice channels. Put very roughly this means that it is more than 1000 times as difficult to transmit the ripple of Julia's silks as it is to transmit her voice.

The use of television is not confined to the provision of your entertainment. In recent years television systems have been used for industrial purposes, usually to permit an operator, controller or observer to see what is going on at a remote point. Naturally the growth in this use is related to the cost, and, as just pointed out, the cost is related to the amount of detail transmitted. Up until now industrial television has been tied to the standards required to transmit the picture of Julia in rippling silks. In the remote viewing of certain operations such as the output of a steel rolling mill it may not be necessary to distinguish the ripple in the workman's overalls. And in viewing street traffic flow, it may be necessary only to see the vehicles, not the ripples in their fenders.

In many cases of industrial applications the amount of required detail is far less than that provided by the standards of broadcast television to which industrial television is currently tied. This suggests the possibility of important economies in industrial television systems, and the elements in the systems that we are primarily concerned with here are the connecting lines. So we will leave the gentle Julia to tell you about the important economies that are possible in the connecting lines and show you several demonstrations that will permit you to judge for yourselves the satisfactoriness of the resulting transmission.

TELEVISION LINE FACILITIES—PRESENT TECHNIQUES

Many television programs originate at remote points, and it is necessary to provide means for transmitting them to the television studio. For example, in Philadelphia, one studio is in the center of town, another in West Philadelphia and a third on City Line, while programs may originate in the Municipal Stadium, Convention Hall, Independence

Square or any number of other places. In the early days of television these program pickups were made over ordinary telephone cable pairs. Figure 1 shows the construction of a large size local telephone cable.

FIG. 1. Ordinary telephone cable.

FIG. 2. Video pair.

However, with the required 4,000,000-cycle bandwidth, the technical difficulties were overwhelming in that amplifiers were necessary at about 1-mile intervals, bridged taps had to be removed and precise equalization was required. Accordingly, operations were limited to the point of impracticability by matters of restrictions on pickup locations and time and expense required in preparation.

It soon became apparent that the demands of the new industry would have to be met by different means. About 1946 the Bell Telephone Laboratories developed a facility known as a video pair which was made available in the forms of separate video cables or as video pairs included in ordinary telephone cables. Figure 2 shows the construction of a video pair. Over the years both types have been placed in Philadelphia, and now there is a network of video pairs which extends to most of the key points of television interest in the City. It is still growing.

Tonight we are concerned with industrial television, not broadcast television, and I should like to tie in what has just been said with the industrial television problem by emphasizing four facts:

1. The video network just described grew largely in connection with normal cable-construction projects.
2. Its provision was possible only because the key points of television interest are fairly limited in number. By way of illustration, there are only about 15,000 video conductor miles in the Bell System compared with some 235 million miles of ordinary cable conductors.
3. Video cable pairs are in the order of 40 to more than 100 times as costly as ordinary pairs.
4. The provision of a video network for complete industrial television coverage would require special construction of enormous proportions.

That is the problem that has restricted the use of industrial television for remote pickups, and it is the one that we sought to solve by looking again to telephone cable pairs as a possible suitable facility. Lest there be some misunderstanding, it should be stated that remote industrial television pickups can be and are being provided at the present time. However, individual special construction or the use of microwave radio is required, and they are, of course, provided on special order and at additional expense.

LINE FACILITIES FOR INDUSTRIAL TELEVISION

The earlier experience with ordinary telephone cable pairs indicated that they are capable of providing video transmission without intermediate amplifiers, extensive modification of the cable plant or expensive equalization if requirements of bandwidth, phase distortion and noise are relaxed. The questions to be answered were (1) how much do the requirements have to be relaxed to achieve real improvements in costs and flexibility, and (2) will the resulting transmission provide a satisfactory picture for the industrial television user.

Without attempting to follow the precise order of our thoughts in attacking the problem, let us consider some of the pertinent information that was available. Based on earlier experience of commercial transmissions over telephone cable pairs at video frequencies, it appeared that a line section loss of 60 db was probably somewhere near the maximum that could be tolerated without the use of a line video amplifier for reinforcement of the signal. Also, engineering judgment indicated that a 250,000-cycle base bandwidth was in the range of a suitable balance between picture results and system economies.

Figure 3 shows a distribution of customer lines for our 80 Philadelphia central offices expressed in terms of 250,000-cycle losses. These are the lines that radiate directly to the customers' premises from the telephone central office buildings. It will be noted that, on the 250,000-cycle loss basis, 98 per cent of these lines are 60 db or less. Considered

in the light of the earlier experience, this means that on 98 per cent of our customer lines, 250,000-cycle video signals could be transmitted between the customers' premises and our central offices without the necessity of intermediate video amplifiers somewhere in the line. Even with the introduction of finer wire conductors in the plant, the 98 per cent should change to not less than 90 per cent in the next ten years. The avoidance of amplifiers in customer lines would eliminate a circuit element that is, at the present time, difficult and costly to provide. The use of amplifiers at central offices, on the other hand, is a standard practice.

As of interest, Fig. 4 shows the losses of the several gauges of cable in our plant at various frequencies. The indicated higher losses at the higher frequencies underlie the problem under discussion. It can be readily understood from these curves that greater bandwidth carries with it increased line amplifier requirements.

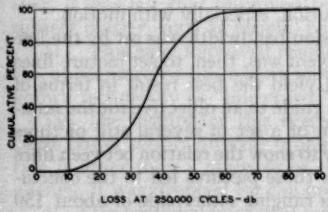

FIG. 3. Distribution of customer line losses at 250,000 cycles.

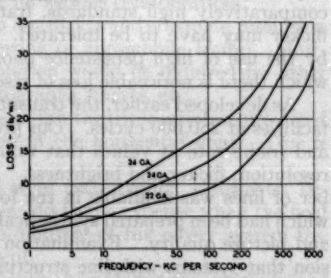

FIG. 4. Loss-frequency characteristics of cable pairs.

Another phase of our original thinking had to do with the question of how much relaxation in the bandwidth requirement could be tolerated. It was possible to perform a very simple experiment based on current broadcast television practice as a standard. That was to view a picture transmitted with the full 4,000,000-cycle band and then insert filters in the circuit and examine the results. We found that with a reduction of received bandwidth to one quarter of the original, that is, to 1,000,000 cycles, picture detail that we were interested in was not lost. It was impracticable to pursue this simple experiment further because the change in resolution resulting from the filtering process is only along the horizontal while the vertical (525 lines) remains unchanged. However, the results encouraged us to expect that, for the specialized applications under consideration, a further reduction in bandwidth of similar proportions, that is, to 250,000 cycles, would not produce an intolerable reduction in detail if distributed between horizontal and vertical resolution.

On the basis, then, of the considerations of line facilities discussed earlier and the experiment just described it was decided to proceed with the 250,000-cycle bandwidth. Suitable equalizers were designed and built so that cable circuits of various lengths could be set up for test purposes.

TERMINAL EQUIPMENT CHARACTERISTICS

There are three important operating characteristics of the terminal equipment that are closely tied in with the transmitted bandwidth; namely, picture lines, frame rate and maximum tolerable brightness. With bandwidth fixed, a change in one of these characteristics reacts either to the benefit or detriment of the others. For example, an increase in the number of lines requires a reduction in frame rate which may increase flicker to the point where a reduction in brightness is required. Similarly, with objectives of lines and brightness set at comparatively high standards, frame rate is correspondingly low and flicker may have to be tolerated. Flicker is subject to some control by the use of high persistence phosphors, but there is a limit beyond which there is noticeable loss of resolution, especially with motion.

As developed earlier, the transmission bandwidth was set by the line facilities at 250,000 cycles. Our problem was, then, to set picture lines and frame rate at values that would yield the best result in terms of resolution, flicker and brightness. A guide to an objective for the number of lines was available in the form of a set of several still pictures which had been prepared synthetically to show the relation between lines and picture quality. Examination of these pictures led to the conclusion that systems with line structures ranging either side of about 150 were candidates. Figure 5 shows the relationship between bandwidth,

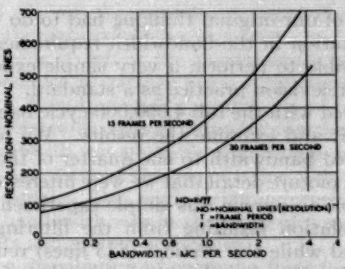

FIG. 5. Resolution *versus* band width.

frame rate and resolution. It will be noted that with a bandwidth of 250,000 cycles and a frame rate of 30 per second (the present television standard) the resolution is less than 150 lines; with a frame rate of 15

per second the resolution is more than 150 lines. This suggested that the suitabilities of different frame rates should be studied. In view of these several considerations the systems shown in Table I were built and

TABLE I.—*Systems Studied.*

System	Bandwidth Cycles	Frames per Second	Fields per Second	Picture Quality Nominal Lines
I	250,000	60	60	87 Non-interlace
II	250,000	30	60	128 Interlace
III	250,000	20	60	157 Triple Interlace
IV	250,000	20	40	157 Interlace
V	250,000	15	30	184 Interlace (Special Phosphor PAF)
VI	250,000	10	30	222 Triple Interlace
	4,000,000	30	60	525 Broadcast TV Interlace

tested. The judgments in regard to these systems were as follows:

I. The resolution was insufficient for serious consideration.

II. This resulted in a picture with low flicker and adequate resolution for many purposes, such as the viewing of automobile traffic. However, it was felt that improved resolution would be required for other subject matter, such as people, photographs, charts, etc.

III. This gave improved resolution, but the triple interlace produced the appearance of downward motion in the horizontal lines. This is known technically as "line crawl."

IV. The results for this system were encouraging. However, because power supply filtering problems add to the expense when the field rate is other than a multiple or sub-multiple of the power system frequency, it was dropped for the present.

V. This provided improved resolution over II, but the improvement was, of course, at the expense of frame rate and therefore flicker. In order to offset the increased flicker, a tube with a PAF—higher persistence—phosphor was built by Du Mont Laboratories. The improved resolution made possible by the slower frame rate yielded a picture that had merit, but reduced brightness was required.

VI. This was unsatisfactory for the same reason as III, that is, objectionable line crawl.

Systems II and V are, then, the ones that were selected for serious consideration, and they will be demonstrated this evening.

A word is in order about the indicated resolution in Table I. It was found impracticable to operate with the line structures shown for Systems II and V with the monitor equipment that was readily available because the size of the scanning spot is gauged to 525 lines and modification of the size of the spot would have required redesign of the electron gun. The result was that, with the reduced number of scanning lines, there were spaces between the lines that were visible at normal viewing distances. This led to a choice of vertical lines somewhat greater than desired at the expense, of course, of horizontal resolution.

Table II shows the compromises that were made in this respect. For System II, 147 vertical lines were used compared with the 128 nominal, with a vertical to horizontal resolution ratio of 1.32. For System V,

TABLE II.—*Systems Adopted.*

System	Frames per Second	Fields per Second	Horizontal Lines	Horizontal Frequency	Ratio Vertical to Horizontal Resolution
II	30	60	147	4410	1.32
V	15	30	225	3375	1.56

225 vertical lines were used compared with the 184 nominal, with a vertical to horizontal resolution of 1.56. The results of these compromises were that satisfactory line fills of the raster were obtained with negligible losses in resolution. This is in accord with earlier experiments by Baldwin[2] which showed that, over fairly wide ranges, subjective sharpness of image evaluations are not sensitive to the vertical-to-horizontal resolution ratio.

DEMONSTRATION

We have planned a demonstration that will serve to illustrate some of the problems that have been discussed in a general way and to show you the results of the work that has been done to date. The two selected systems have been set up, each with connecting lines made up of ordinary telephone cable pairs.

Figure 6 shows the terminal equipment arrangements, which are es-

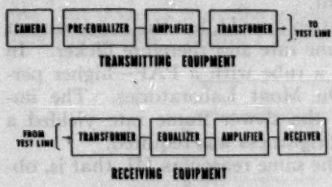

FIG. 6. Demonstration arrangements, terminating equipment.

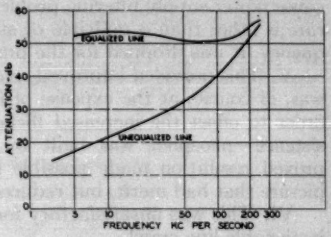

FIG. 7. Loss-frequency characteristics of test line.

sentially the same for each case. The various equipment items other than the camera and receiver are associated with the line facilities, and their functions are briefly as follows:

Transmitting Amplifier:

Raises camera output voltage to a level that will insure satisfactory signal to noise ratio on the line.

[2] See "The Subjective Sharpness of Simulated Television Images," by M. W. Baldwin, *Bell System Tech. Jour.*, Vol. XIX, pp. 563–586 (1940).

Equalizer:

Introduces loss that varies with frequency in a manner that is complementary to the line loss-frequency characteristic. The objective is an over-all loss that is essentially flat at the 250,000-cycle line loss value.

Receiving Amplifier:

Provides sufficient gain to offset the equalized line loss so that the input level requirements of the receiver are met.

Transformer:

Matches unbalanced (to ground) equipment circuits to balanced line.

Figure 7 shows the loss-frequency characteristic of one of the test lines used in the experimental work. Time limitations made it impossible to include a similar curve for the circuits used in the demonstration. The unequalized and equalized characteristics are both shown, and the degree of the success of the equalization is measured by the variation in loss with frequency. It will be noted that the line is flat within plus or minus 2.5 db. Reduction of this variation involves equalizer equipment complication and expense that does not appear justified by the results. This judgment is based on a comparison between transmissions with terminal equipments operating "back-to-back" and with the equalized line inserted between them.

In the first demonstration the camera and receiver are both here in the lecture hall, and they are operating with a frame rate of 15 per second and a field rate of 30 per second. The PAF phosphor mentioned earlier is used in the receiver. Line facilities, shown in Fig. 8, are made

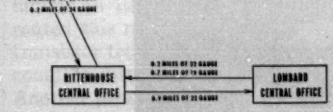

FIG. 8. Demonstration arrangements, Bell Telephone Company facilities, System V. 3.2 miles, 44.3 db at 0.25 mc.

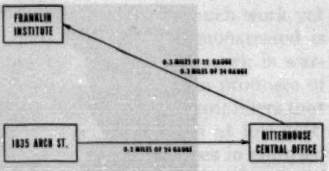

FIG. 9. Demonstration arrangements, Bell Telephone Company facilities, System II. 0.9 mile, 14.4 db at 0.25 mc.

up of ordinary cable pairs the entire distance although the sections between the Rittenhouse and Lombard central offices are in trunk plant.

In the second demonstration, the camera is located in the Headquarters Building of the Telephone Company at 1835 Arch Street, and the

System II—128 nominal lines, 30 frames per second, 60 fields per second.

Typical current industrial television system.

System V—184 nominal lines, 15 frames per second, 30 fields per second.

FIG. 10. Picture quality *versus* lines.

receiver is in the lecture hall. Frame and field rates of 30–60 respectively are used. Line facilities, shown in Fig. 9, are made up entirely of the two central office lines between The Franklin Institute and the Rittenhouse central office and 1835 Arch Street and the Rittenhouse central office.

For record purposes in this paper, Fig. 10 shows photographs of pictures televised over the systems demonstrated using the line facilities with characteristics shown in Fig. 7. A photograph transmitted over a typical current industrial television system on a back-to-back basis is included for comparison purposes.

COUPLING BETWEEN CABLE PAIRS

The close proximity of pairs in a cable with up to 1800 pairs packed into a sheath less than 3 in. in diameter causes inductive and capacitive coupling between pairs. The result of this is that a transmission path exists between pairs, and, therefore, a signal in one pair produces a signal in the others. The magnitude of the signal in the disturbed pair is directly proportional to the coupling between it and the disturbing pairs, and it appears as crosstalk or noise. Inter-pair coupling can also produce another undesired effect where amplification is involved in that it may offer a feedback path between the amplifier output and input, and if the coupling is great enough unstable operation will occur. Since the coupling between pairs increases with frequency, it may present serious problems at video frequencies.

The investigation of these effects involves fairly extensive quantitative measurements but as of the date of this paper, only a limited number have been made.

CONCLUSIONS

You have seen tonight the quality of television pictures that can be transmitted over relatively low cost telephone cable pairs with a bandwidth of 250,000 cycles. We acknowledge that there is much work yet to be done. For example, transmission of the type demonstrated is limited to 10–15 miles; however, if further development work is warranted this range could be extended. Also, there are the promises of transistor techniques which may make possible miniature amplifiers that could be installed in manholes with increased bandwidth at low cost. Another future possibility is the use of sampling techniques in contrast to the analogue techniques used to date; this, too, promises increased bandwidth over telephone cable pairs. For the terminal equipment, further work directed toward the following may be profitable: improved phosphors, lower frame rates, elimination of spaces between lines by the use of larger spot or "spot wobble," and different scanning techniques.

The fields of application of the systems demonstrated remain to be determined by the evaluations of prospective users. Probably these

are interim systems on the path toward future systems that will offer improved picture quality at attractive costs. Toward that end, it is hoped that the results demonstrated will encourage further work on the part of all those interested.

In any event, for this or any industrial television system to survive, it must meet the competition of the market place; that is, it must have customer acceptance at a price that customers are willing to pay.

Acknowledgments

We wish to acknowledge the cooperation of Dage Television Division of Thompson Products, Inc. and General Precision Laboratory, Inc. who built the equipment and who participated in many of the tests of the various systems. John Mullen by his enthusiasm contributed much to the decision to go ahead with the work.

A. D. Fowler of the Bell Telephone Laboratorites offered valuable advice on the design and construction of line equalizers.

Credit is due to many colleagues, particularly E. M. Lewis III, Marvin Galloway and W. H. Beaumont. Thanks are due L. Fink III and W. E. Darnell for assistance in the preparation of the paper and A. L. Charny and J. E. Murdoch whose encouragement and approval enabled the experiments to be carried out.

GRAVITATIONAL TORQUE ON A SATELLITE VEHICLE

BY

ROBERT E. ROBERSON [1]

ABSTRACT

Using a potential function for a small rigid body in the field of an oblate spheroid developed previously by Roberson and Tatistcheff, the gravitational torque on a satellite vehicle in the field of the earth is found. Results are the torque components along the satellite principal axes. The defining relationships are not completely reduced for large angular motions of the satellite, but torque components are found explicitly in terms of the angles of attitude deviation from a desired attitude reference for the small-angle case.

INTRODUCTION

As I have discussed elsewhere (1),[2] the gravitational torque exerted by the earth on a satellite vehicle is of fundamental concern to the problem of controlling the attitude of the vehicle. The purpose of this paper is to derive the torque components along the principal axes of inertia of the satellite.

The derivation is based on the form for the potential function for a small rigid body in the field of the earth, considered as an oblate spheroid, given previously in (2). An expression for U is given as Eq. 7 in terms of inertia dyadic components $I_{\xi\xi}$, $I_{\eta\eta}$ and $I_{\zeta\zeta}$. These are given in terms of components of an attitude deviation matrix by Eq. 5. Torque components in terms of derivatives of U with respect to the attitude angles are expressed by Eq. 9. These three equations completely describe the torque components as functions of the attitude angles, but it is difficult to display the relationships explicitly for the large angle case.

However, if deviations from a reference attitude are assumed small, explicit forms for the torque components are found as Eqs. 14–16. These involve coefficients which depend on the reference system chosen and the motion of the satellite, the general forms of which are given as Eqs. 17–22. Simplified forms for certain additional small angle approximations are given as Eqs. 23–28.

THE POTENTIAL FUNCTION

Let ζ denote the axes from the center of the earth through the satellite, η denote the northerly direction at the satellite, and ξ be chosen so that the relation $\bar{e}_\xi = \bar{e}_\eta \times \bar{e}_\zeta$ holds among the unit vectors along these axes. ($\xi\eta\zeta$ are respectively the axes xyz of (2).) Denote the radial

[1] Autonetics Division, North American Aviation, Inc., Downey, Calif.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

distance of the satellite from the earth by r, its geocentric latitude by λ. Also, K is the product of the mass of the earth by the gravitational constant, a is the polar radius of the earth, and μ is a form factor for the earth (a coefficient of the second spherical harmonic in the potential function of the earth), numerically equal to 5.46×10^{-4}.

Then from (2), Eqs. 17 and 18, the potential function of the satellite in the field of the earth can be written

$$U = \frac{K}{2r^3}[2I_{\xi\xi} - I_{\xi\xi} - I_{\eta\eta} + I_1 + I_2 + I_3] + \frac{3\mu Ka^2}{2r^5}[(5 - 27\sin^2\lambda)I_{\xi\xi} - 2\cos^2\lambda I_{\eta\eta} + 8\sin 2\lambda I_{\eta\xi}] \quad (1)$$

where I_1, I_2, I_3 are the principal moments of inertia of the satellite and $I_{\xi\xi}$, $I_{\eta\xi}$ etc. are components of the inertia dyadic $\bar{\bar{I}}$ equal to $I_{\xi\xi} = \bar{e}_\xi \cdot \bar{\bar{I}} \cdot \bar{e}_\xi$, $I_{\eta\xi} = \bar{e}_\eta \cdot \bar{\bar{I}} \cdot \bar{e}_\xi$, etc.

In order to obtain the torque components about the principal axes it is necessary to express these inertia dyadic components in terms of the attitude rotation angles and to differentiate U with respect to these rotation angles.

ATTITUDE REFERENCE SYSTEMS

Let us review briefly some of the most important information about the attitude reference coordinate systems presented in (1). The motion of a satellite can be described by angles α and β with reference to an orbital plane inclined at an angle γ to the earth's equator. In Fig. 1 this satellite position is labeled S, the direction from the center of the earth to S being the ζ defined previously.

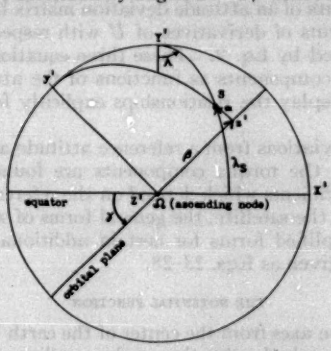

FIG. 1. Position angles of the satellite.

The axes $x'y'z'$ (x' so defined that $\bar{e}_{z'} = \bar{e}_{y'} \times \bar{e}_{x'}$, y' and z' being as shown in Fig. 1) form a first basic reference system for satellite attitude motions. Generally z' is a kind of "up" and x' is a kind of "forward" direction to a satellite-fixed observer, provided the lateral departure α from the orbital plane remains quite small, as it must if the orbital plane is properly defined for the motion.

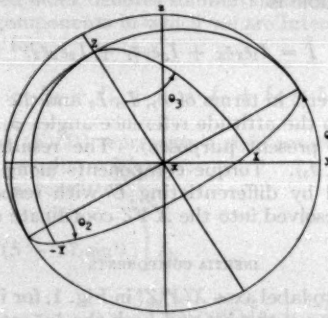

FIG. 2. Attitude deviation angles.

However, as discussed in (1), one generally desires to use a more sophisticated attitude reference system xyz. Possible definitions of it are treated in that reference. Of concern here is just the fact that it usually is a set which can be obtained from $x'y'z'$ by a small angle rotation.[3] The relationship between xyz and $x'y'z'$ is defined by the direc-

TABLE I.—*Reference System Direction Cosine Matrices.*

(A)	x	y	z
x'	1	$-\phi_3$	ϕ_2
y'	ϕ_3	1	$-\phi_1$
z'	$-\phi_2$	ϕ_1	1

(B)	X	Y	Z
x	$\cos\theta_2 \cos\theta_3$	$-\cos\theta_2 \sin\theta_3$	$\sin\theta_2$
y	$\sin\theta_1 \sin\theta_2 \cos\theta_3 + \cos\theta_1 \sin\theta_3$	$\cos\theta_1 \cos\theta_3 - \sin\theta_1 \sin\theta_2 \sin\theta_3$	$-\sin\theta_1 \cos\theta_2$
z	$-\cos\theta_1 \sin\theta_2 \cos\theta_3 + \sin\theta_1 \sin\theta_3$	$\sin\theta_1 \cos\theta_3 + \cos\theta_1 \sin\theta_2 \sin\theta_3$	$\cos\theta_1 \cos\theta_2$

tion cosine matrix (A) of Table I, in which ϕ_1, ϕ_2, and ϕ_3 are small angles. It is assumed that these angles are uniquely specified by the geometric position of the satellite, and perhaps time, after a definite choice for xyz has been made.

Once given the reference axes, it is possible to define a set of attitude deviation angles which describe the departure of the satellite from its

[3] An outstanding case in which this is not true is where an inertially fixed xyz reference is desired. It will be seen later that the present treatment can easily be made to encompass the large angle case.

reference orientation xyz. Let XYZ be principal axes of the satellite, such that X coincides with x, Y with y, and Z with z when the attitude deviations vanish. Define attitude angles θ_1, θ_2, θ_3 between these two sets of axes as shown by the unit sphere diagram of Fig. 2. The corresponding direction cosine matrix is shown as (B) of Table I.

The procedure now is as follows. Inasmuch as XYZ are principal axes, the inertia dyadic is

$$\bar{\bar{I}} = I_1 \bar{e}_X \bar{e}_X + I_2 \bar{e}_Y \bar{e}_Y + I_3 \bar{e}_Z \bar{e}_Z. \tag{2}$$

We first express $I_{\xi\xi}$ etc. in terms of I_1, I_2, I_3 and the attitude deviation angles θ_1, θ_2, θ_3 (also the attitude reference angles ϕ_1, ϕ_2, ϕ_3, but this is immaterial for our present purposes). The results substituted into Eq. 1 give $U(\theta_1, \theta_2, \theta_3)$. Torque components along the axes of these angles are obtained by differentiating U with respect to the angles. Finally, these are resolved into the XYZ coordinate system.

INERTIA COMPONENTS

It is convenient to label axes $X'Y'Z'$ in Fig. 1, for it is easy to express the relationship between this set and both the $\xi\eta\zeta$ set and the $x'y'z'$ set. The results are given as direction cosine matrices (C) and (D) of Table II. By matrix multiplication, (E) of Table II is found relating $\xi\eta\zeta$ and

TABLE II.—*Direction Cosine Matrices for* $\xi\eta\zeta \rightarrow X'Y'Z' \rightarrow x'y'z'$.

(C)	X'	Y'	Z'
ξ	$\cos\Lambda$	0	$-\sin\Lambda$
η	$-\sin\lambda\sin\Lambda$	$\cos\lambda$	$-\sin\lambda\cos\Lambda$
ζ	$\cos\lambda\sin\Lambda$	$\sin\lambda$	$\cos\lambda\cos\Lambda$

(D)	x'	y'	z'
X'	$\cos\gamma\cos\beta$	$-\sin\gamma$	$\cos\gamma\sin\beta$
Y'	$\sin\gamma\cos\beta$	$\cos\gamma$	$\sin\gamma\sin\beta$
Z'	$-\sin\beta$	0	$\cos\beta$

(E)	x'	y'	z'
ξ	$(\cos\alpha\cos\gamma - \sin\alpha\sin\gamma\sin\beta)/\cos\lambda$	$-\sin\gamma\cos\alpha\cos\beta/\cos\lambda$	$\sin\gamma\sin\alpha\cos\beta/\cos\lambda$
η	$-\sin\gamma\cos\beta/\cos\lambda$	$(\cos\gamma\cos\alpha - \sin\gamma\sin\alpha\sin\beta)\cos\alpha/\cos\lambda$	$(\sin\gamma\sin\beta\sin\alpha - \cos\gamma\cos\alpha)\sin\alpha/\cos\lambda$
ζ	0	$\sin\alpha$	$\cos\alpha$

$x'y'z'$ directly. In obtaining these results, one needs

$$\sin\lambda = \sin\alpha\cos\gamma + \cos\alpha\sin\gamma\sin\beta \tag{3}$$

$$\left.\begin{aligned} \cos\Lambda &= \cos\alpha\cos\beta/\cos\lambda \\ \sin\Lambda &= (\cos\alpha\sin\beta\cos\gamma - \sin\gamma\sin\alpha)/\cos\lambda \end{aligned}\right\} \tag{4}$$

Note that the elements of (E), like those of (A), are prescribed time functions, depending only on the gross motion of the satellite's center of mass and not on its attitude motion.

Denote by F the matrix product (E)(A) and by F_{ij} the element of (F) in the i^{th} row, j^{th} column. Then

$$\left.\begin{aligned} I_{\xi\xi} &= I_1(F_{1k}B_{k1})^2 + I_2(F_{1k}B_{k2})^2 + I_3(F_{1k}B_{k3})^2 \\ I_{\eta\eta} &= I_1(F_{2k}B_{k1})^2 + I_2(F_{2k}B_{k2})^2 + I_3(F_{2k}B_{k3})^2 \\ I_{\zeta\zeta} &= I_1(F_{3k}B_{k1})^2 + I_3(F_{3k}B_{k2})^2 + I_3(F_{3k}B_{k3})^2 \\ I_{\eta\zeta} &= I_1(F_{2k}B_{k1})(F_{3k}B_{k1}) + I_2(F_{2k}B_{k2})(F_{3k}B_{k2}) + I_3(F_{2k}B_{k3})(F_{3k}B_{k3}) \end{aligned}\right\} \quad (5)$$

in which the repeated index denotes summation over $k = 1, 2, 3$.

The particular components in which we are interested for Eq. 1 are only $I_{\eta\eta}$, $I_{\eta\zeta}$ and $I_{\zeta\zeta}$, for

$$2I_{\zeta\zeta} - I_{\xi\xi} - I_{\eta\eta} + I_1 + I_2 + I_3 = 3I_{\zeta\zeta}. \quad (6)$$

This follows because (F)(B) represents a rigid rotation and the sum of squares of any row or column is unity.

Thus Eq. 1 can be rewritten

$$U = \frac{3K}{2r^3}\left[1 + \mu\frac{a^2}{r^2}(5 - 27\sin^2\lambda)\right] I_{\zeta\zeta} - \frac{3\mu Ka^2}{r^5}\cos^2\lambda I_{\eta\eta} + \frac{12\mu Ka^2}{r^5}\sin 2\lambda I_{\eta\zeta} \quad (7)$$

with the inertia dyadic components obtained from Eq. 5.

TORQUE COMPONENTS

The axes of the angles $\theta_1, \theta_2, \theta_3$ are respectively $\bar{e}_x$, $\bar{e}_0 = \bar{e}_y\cos\theta_1 + \bar{e}_z\sin\theta_1$ and $\bar{e}_Z$. It follows that the gravitational torque on the satellite is

$$L = -\frac{\partial U}{\partial\theta_1}\bar{e}_x - \frac{\partial U}{\partial\theta_2}(\bar{e}_y\cos\theta_1 + \bar{e}_z\sin\theta_1) - \frac{\partial U}{\partial\theta_3}\bar{e}_Z. \quad (8)$$

Thus the torque components along the principal axes are

$$\left.\begin{aligned} L_X &= -\frac{\partial U}{\partial\theta_1}\cos\theta_2\cos\theta_3 - \frac{\partial U}{\partial\theta_2}\sin\theta_3 \\ L_Y &= \frac{\partial U}{\partial\theta_1}\cos\theta_2\sin\theta_3 - \frac{\partial U}{\partial\theta_2}\cos\theta_3 \\ L_Z &= -\frac{\partial U}{\partial\theta_1}\sin\theta_2 - \frac{\partial U}{\partial\theta_3} \end{aligned}\right\} \quad (9)$$

The potential function to be differentiated is given by Eq. 7.

SMALL ANGLE CASE

Thus far, there have been no essential restrictions on the analysis. Even the ϕ-angles, assumed to be small, appear only in the matrix product F, and this product could just have well been obtained for a large-angle relationship between xyz and $x'y'z'$.

It is a detail to complete the derivation of the L components from this point. The large angle case is tedious, of course, and not particularly instructive—nevertheless, it can be carried through formally if it is really needed. However, a case of special interest is that in which the angles θ_1, θ_2, and θ_3 are so small that their squares and cross-products can be neglected.

For this small angle case, one finds

$$\frac{\partial I_{rr}}{\partial \theta_1} = 2(I_2 - I_3)F_{32}F_{33} + 2(I_3 - I_3)(F_{32}^2 - F_{33}^2)\theta_1 + 2(I_1 - I_3)F_{31}F_{32}\theta_2 + 2(I_1 - I_2)F_{31}F_{33}\theta_3 \quad (10)$$

$$\frac{\partial I_{rr}}{\partial \theta_2} = 2(I_3 - I_1)F_{31}F_{33} + 2(I_1 - I_3)F_{31}F_{32}\theta_1 + 2(I_1 - I_3)(F_{33}^2 - F_{31}^2)\theta_2 + 2(I_2 - I_1)F_{32}F_{33}\theta_3 \quad (11)$$

$$\frac{\partial I_{rr}}{\partial \theta_3} = 2(I_1 - I_2)F_{31}F_{32} + 2(I_1 - I_2)F_{31}F_{33}\theta_1 + 2(I_2 - I_1)F_{32}F_{33}\theta_2 + 2(I_1 - I_2)(F_{32}^2 - F_{31}^2)\theta_3. \quad (12)$$

The corresponding partial derivatives of I_{ww} are identical except that the 3 in the row subscript of all the F-components is replaced by a 2. Also, the derivatives of I_{wr} are again of the same form in which the combinations of F_{ij} in Eqs. 10–12 are replaced as follows:

$$\left.\begin{aligned} F_{31}^2 &\to F_{21}F_{31};\ 2F_{31}F_{33} \to F_{21}F_{32} + F_{22}F_{31} \\ F_{32}^2 &\to F_{22}F_{32};\ 2F_{31}F_{33} \to F_{21}F_{33} + F_{23}F_{31} \\ F_{33}^2 &\to F_{23}F_{33};\ 2F_{32}F_{33} \to F_{22}F_{33} + F_{23}F_{32} \end{aligned}\right\} \quad (13)$$

Collecting these results in Eqs. 7 and 9, we have the final expressions for the torque components

$$L_X = -\frac{3K}{r^3}[(I_2 - I_3)A_0 + (I_3 - I_3)A_1\theta_1 + (I_1 - I_3)A_2\theta_2 + (I_3 - I_2)A_3\theta_3] \quad (14)$$

$$L_Y = -\frac{3K}{r^3}[(I_3 - I_1)A_3 + (I_1 - I_3)A_2\theta_1 + (I_1 - I_3)A_4\theta_2 + (I_3 - I_1)A_0\theta_3] \quad (15)$$

$$L_z = -\frac{3K}{r^3}[(I_1 - I_2)A_3 + (I_1 - I_2)A_3\theta_1 + (2I_3 - I_1 - I_3)A_0\theta_2 + (I_1 - I_2)A_3\theta_3] \quad (16)$$

where

$$A_0 = F_{32}F_{33} + \mu\frac{a^2}{r^2}[(5 - 27\sin^2\lambda)F_{32}F_{33} - 2\cos^2\lambda F_{22}F_{23} + 4\sin 2\lambda(F_{22}F_{33} + F_{23}F_{32})] \quad (17)$$

$$A_1 = (F_{33}^2 - F_{32}^2) + \mu\frac{a^2}{r^2}[(5 - 27\sin^2\lambda)(F_{33}^2 - F_{32}^2) - 2\cos^2\lambda(F_{23}^2 - F_{22}^2) + 8\sin 2\lambda(F_{23}F_{33} - F_{22}F_{32})] \quad (18)$$

$$A_2 = F_{31}F_{32} + \mu\frac{a^2}{r^2}[(5 - 27\sin^2\lambda)F_{31}F_{32} - 2\cos^2\lambda F_{21}F_{22} + 4\sin 2\lambda(F_{21}F_{32} + F_{22}F_{31})] \quad (19)$$

$$A_3 = F_{31}F_{33} + \mu\frac{a^2}{r^2}[(5 - 27\sin^2\lambda)F_{31}F_{33} - 2\cos^2\lambda F_{21}F_{23} + 4\sin 2\lambda(F_{21}F_{33}) - F_{23}F_{31})] \quad (20)$$

$$A_4 = (F_{33}^2 - F_{31}^2) + \mu\frac{a^2}{r^2}[(5 - 27\sin^2\lambda)(F_{33}^2 - F_{31}^2) - 2\cos^2\lambda(F_{23}^2 - F_{21}^2) + 4\sin 2\lambda(F_{23}F_{33} - F_{21}F_{31})] \quad (21)$$

$$A_5 = (F_{32}^3 - F_{31}^3) + \mu\frac{a^2}{r^2}[(5 - 27\sin^2\lambda)(F_{32}^2 - F_{31}^2) - 2\cos^2\lambda(F_{22}^2 - F_{21}^2) + 4\sin 2\lambda(F_{22}F_{32} - F_{21}F_{31})]. \quad (22)$$

The development in no way restricts the size of the F_{ij} components. If, however, one can also neglect squares and products of the small angles α, ϕ_1, ϕ_2, ϕ_3, F takes the form shown in Table III. If products

TABLE III.—*The Direction Cosine Matrix $\xi\eta\zeta \rightarrow xyz$ for Small Angles.*

(F)	x	y	z
ξ	$(\cos\gamma - \phi_3\sin\gamma\cos\beta - \alpha\sin\gamma\sin\beta)/\cos\lambda$	$(-\sin\gamma\cos\beta - \phi_3\cos\gamma)/\cos\lambda$	$[\phi_2\cos\gamma + (\phi_1+\alpha)\sin\gamma\cos\beta]/\cos\lambda$
η	$(\sin\gamma\cos\beta + \phi_3\cos\gamma)/\cos\lambda$	$(\cos\gamma - \phi_3\sin\gamma\cos\beta - \alpha\sin\gamma\sin\beta)/\cos\lambda$	$[\phi_2\sin\gamma\cos\beta - (\phi_1+\alpha)\cos\gamma]/\cos\lambda$
ζ	$-\phi_2$	$\phi_1+\alpha$	1

of μ by these small angles also are neglected, the corresponding forms for the A_i are

$$A_0 = \phi_1 + \alpha + 8\mu\frac{a^2}{r^2}\sin\gamma\cos\gamma\sin\beta \quad (23)$$

$$A_1 = 1 + \mu\frac{a^2}{r^2}(5 - 27\sin^2\lambda + 2\cos^2\gamma) \quad (24)$$

$$A_2 = -2\mu \frac{a^2}{r^2} \sin\gamma \cos\gamma \cos\beta \tag{25}$$

$$A_3 = -\phi_2 + 8\mu \frac{a^2}{r^2} \sin^2\gamma \sin\beta \cos\beta \tag{26}$$

$$A_4 = 1 + \mu \frac{a^2}{r^2} (5 - 27 \sin^2\lambda + 2 \sin^2\gamma \cos^2\beta) \tag{27}$$

$$A_5 = -2\mu \frac{a^2}{r^2} (\cos^2\gamma - \sin^2\gamma \cos^2\beta) \tag{28}$$

If Eqs. 23–28 are used in Eqs. 14–16, one finds the complete torque expressions corresponding to the small angle case. They are

$$\begin{aligned} L_X = -\frac{3K}{r^3}\Big[& (I_2 - I_3)(\phi_1 + \alpha + 8\mu \frac{a^2}{r^2} \sin\gamma \cos\gamma \sin\beta) \\ & + (I_2 - I_3)(1 + \mu \frac{a^2}{r^2} \{5 - 27 \sin^2\lambda + 2 \cos^2\gamma\})\theta_1 \\ & + (I_3 - I_1)2\mu \frac{a^2}{r^2} \sin\gamma \cos\gamma \cos\beta\theta_2 \\ & + (I_3 - I_2)(-\phi_2 + 8\mu \frac{a^2}{r^2} \sin^2\gamma \sin\beta \cos\beta)\theta_3\Big] \end{aligned} \tag{29}$$

$$\begin{aligned} L_Y = -\frac{3K}{r^3}\Big[& (I_3 - I_1)(-\phi_2 + 8\mu \frac{a^2}{r^2} \sin^2\gamma \sin\beta \cos\beta) \\ & + (I_3 - I_1)2\mu \frac{a^2}{r^2} \sin\gamma \cos\gamma \cos\beta\theta_1 \\ & + (I_1 - I_3)(1 + \mu \frac{a^2}{r^2} \{5 - 27 \sin^2\lambda + 2 \sin^2\gamma \cos^2\beta\})\theta_2 \\ & + (I_3 - I_1)(\phi_1 + \alpha + 8\mu \frac{a^2}{r^2} \sin\gamma \cos\gamma \sin\beta)\theta_3\Big] \end{aligned} \tag{30}$$

$$\begin{aligned} L_Z = -\frac{3K}{r^3}\Big[& (I_2 - I_1)2\mu \frac{a^2}{r^2} \sin\gamma \cos\gamma \cos\beta \\ & + (I_1 - I_2)(-\phi_2 + 8\mu \frac{a^2}{r^2} \sin^2\gamma \sin\beta \cos\beta)\theta_1 \\ & + (2I_2 - I_1 - I_3)(\phi_1 + \alpha + 8\mu \frac{a^2}{r^2} \sin\gamma \cos\gamma \sin\beta)\theta_2 \\ & + (I_2 - I_1)2\mu \frac{a^2}{r^2} (\cos^2\gamma - \sin^2\gamma \cos^2\beta)\theta_3\Big]. \end{aligned} \tag{31}$$

The dominant terms in these equations are

$$L_X = -\frac{3K}{r^3}(I_2 - I_3)\theta_1 \tag{32}$$

$$L_Y = -\frac{3K}{r^3}(I_1 - I_3)\theta_2 \tag{33}$$

all others being of first order in ϕ_1, ϕ_2, ϕ_3, α, or μ. To evaluate the small terms it should be observed that to within first order in the orbital eccentricity r = constant and $\beta = \omega_0 t$ + constant, where ω_0 is the orbital angular velocity.

CONCLUDING REMARKS

Several interesting things appear from the equations above. First, the position $\theta_1 = \theta_2 = \theta_3 = 0$ is generally not a position of equilibrium. Because these deviation angles are measured from reference axes which are not aligned in a particular way with the gravitational field vector, there is a net torque on the satellite even when it is in its "correct" or "nominal" attitude. It follows that this torque must be countered if the desired attitude is to be maintained.

It occurs to one that a suitable choice of reference axes might be made so as to reduce this torque to zero.[4] This requires choosing ϕ_1, ϕ_2, and ϕ_3 such that $A_0 = A_2 = A_3 = 0$. This cannot be done, at least for small ϕ_1, ϕ_2 and ϕ_3. For, although ϕ_1 can be chosen from Eq. 23 to make $A_0 = 0$, and ϕ_2 from Eq. 26 to make $A_3 = 0$, A_2 is independent of the reference coordinates and persists no matter what their choice. It enters as a (yaw-producing) torque about the Z-axis; unless, however, the satellite has cylindrical symmetry with $I_1 = I_2$, in which case this torque component does vanish.

Even in the special case when $\theta_1 = \theta_2 = \theta_3 = 0$ is a position of equilibrium, the stability of equilibrium depends on the relative magnitudes of the three principal moments of inertia. This point is discussed further in (1).

It is worth noting that the A_i are generally time variable, so that if these gravitational torques are inserted into the attitude equations of motion of a satellite they will introduce parametric excitation terms into the equations. These terms are inherent and cannot all be removed by a proper choice of reference coordinates.

Finally, it should be recognized that in general the principal moments of inertia are not constant because of moving parts internal to the satellite. This topic is discussed in (3), where the equivalent perturbation torques of these moving parts is described. The only change required in the argument of the present paper to account for this effect is to re-

[4] This is not necessarily desirable from other points of view, of course.

place I_1, I_2, and I_3 by the sum of their constant and time-variable parts. The latter give second order small quantities (in the small angle case) and can be ignored, except where they enter Eqs. 32 and 33.

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POLYGONAL ACTION IN CHAIN DRIVES

BY

S. MAHALINGAM [1]

ABSTRACT

The speed of a chain is subject to periodic fluctuations, even for a constant speed of the driving sprocket, due to the fact that a chain lying on a sprocket forms a polygon rather than a circle. It is shown that the dynamic loading of the chain due to this "polygonal action" is similar to that of a simple forced vibration where, beyond a certain critical speed, higher speeds produce lower dynamic loads.

NOTATION

R = radius of sprocket (to center of chain pin)
T = number of teeth in sprocket
n = mean speed of sprocket in rad. per sec.
τ = period of tooth engagement = $\frac{2\pi}{nT}$
p = circular frequency of tooth engagement = nT rad. per sec.
l = length of chain
I = moment of inertia of driven system about axis of rotation
k = longitudinal stiffness of unsupported length of chain

The suffixes 1 and 2 refer to the driving and driven system, respectively.

INTRODUCTION

When the driving sprocket of a chain drive runs at constant speed, the speed of the chain itself is not constant but is subject to periodic fluctuations. This fluctuation, which is caused by the fact that the chain when wrapped on a sprocket forms a polygon rather than a circle, is known as polygonal action.

One effect of polygonal action is to produce a periodic variation in the velocity ratio of the drive, and if the frequency of this variation coincides with a resonant frequency of the system, large stresses may occur. In this respect the chain drive is similar to a Hooke's joint. Another product of the geometry of the chain drive is impact. The cause of impact is the difference in the velocities of the point on the roller and the point on the sprocket that come into contact. Polygonal action is continuous being characterized by small fluctuations, while impact represents a sharp blow of short duration. At high chain speeds the effects of impact are very complex; each impact sets up a train of travelling waves which, after reflection at the sprockets, combine with the next train and so on. The resultant "surge" of the chain completely

[1] Department of Mechanical Engineering, University of Ceylon, Colombo, Ceylon.

predominates the dynamic effects of polygonal action. It would therefore be very difficult to separate the two factors at high speeds.

At low speeds, however, the impulsive loads are small and, owing to the longer interval between impacts, the travelling waves are damped out. Then under certain conditions the dynamic load due to polygonal action is of great importance and an analysis of this factor is made below.

Some aspects of polygonal action have been discussed in recent years. In a paper on the use of chain drives in marine diesel engines, Bremer[2] referred to the fluctuation of the chain speed and to minimize it he recommended sprockets of at least about 30 teeth. The variation of the angular speed of the driven sprocket was studied by Morrison.[3] In his analysis the drive was considered as being equivalent to a series of four-bar-linkages, each acting for a period equal to the period of tooth engagement.

The analysis given below deals with the dynamic load in the chain strand, taking into consideration the elasticity of the chain and the moment of inertia of the driven system. It is shown that the effect of polygonal action is similar to that of a forced vibration.

ANALYSIS

In the following analysis it will be assumed that the driving sprocket runs at a constant speed of n_1 rad. per sec. The reference axes, taken at O_1, will be parallel and perpendicular to the direct common tangent to the pitch circles of the sprockets. The change of slope of the chain will be neglected.

In Fig. 1, A_1 and A_2 represent the pins that are articulating and therefore $O_1A_1A_2O_2$ represents the equivalent four-bar-mechanism. Angles $B_1O_1C_1$ and $B_2O_2C_2$ represent the range of operation of the linkage. The exact formula for $\dot{\theta}_2$, assuming A_1A_2 to be rigid, as given in (3) is extremely cumbersome and an approximate value may be obtained as follows:

$$\text{Speed of chain} \simeq n_1 R_1 \sin\theta_1$$

Hence

$$\dot{\theta}_2 \simeq n_1 \frac{R_1 \sin\theta_1}{R_2 \sin\theta_2}. \tag{1}$$

In practice this method usually gives a high degree of accuracy because the angles $B_1O_1C_1$ and $B_2O_2C_2$ are small and the change in the slope of A_1A_2 is negligible.

When two equal sprockets are used at a distance apart equal to an integral multiple of the pitch, then $R_1 \sin\theta_1$ is always equal to $R_2 \sin\theta_2$, and $\dot{\theta}_2$ is constant. In all other cases $\dot{\theta}_2$ will be subject to small fluctuations.

[2] N. C. BREMER, "Heavy Duty Chain Drives for Marine Propulsion Service," *Trans. A.S.M.E.*, Vol. 69, pp. 441–452 (1947).

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The elasticity of the chain will now be considered. Since each four-bar-linkage operates for a period $\tau = \frac{2\pi}{n_1 T_1} = \frac{2\pi}{n_2 T_2}$, the quantity $R_1 \sin \theta_1$ is a function of period τ and can therefore be expressed as a Fourier series. If we include only the fundamental harmonic term of the series, then it may be shown that

$$R_1 \sin \theta_1 \doteq R_1 \frac{T_1}{\pi} \sin \frac{\pi}{T_1} \left| 1 - \frac{2}{T_1^2 - 1} \cos pt \right| \tag{2}$$

where $p = n_1 T_1 = n_2 T_2$, and t represents time.

In most power transmitting sprockets the number of teeth is never less than about 15 and therefore the coefficient $\frac{2}{T_1^2 - 1}$ may be regarded as a small quantity.

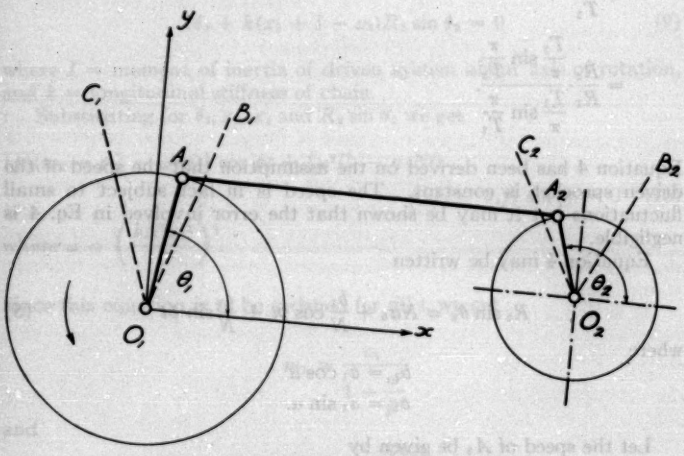

FIG. 1. Equivalent four-bar linkage in chain drive.

Equation 2 may be written in a simpler form as

$$R_1 \sin \theta_1 \doteq a_0 + a_1 \cos pt.$$

The speed of A_1 is then given by

$$-\dot{x}_1 \doteq n_1 (a_0 + a_1 \cos pt)$$

and by integration

$$-x_1 \doteq n_1\left(a_0 t + \frac{a_1}{p}\sin pt\right) + A \tag{3}$$

where A is the constant of integration. In a similar manner it may be shown that

$$R_2 \sin\theta_2 \doteq Na_0 + \frac{a_1}{N}\cos(pt - \alpha) \tag{4}$$

where

α = a "phase angle" corresponding to the fractional pitch in the direct common tangent to the pitch circles.

N = speed ratio

$$= \frac{T_2}{T_1}$$

$$= \frac{R_2}{R_1}\cdot\frac{\frac{T_2}{\pi}\sin\frac{\pi}{T_2}}{\frac{T_1}{\pi}\sin\frac{\pi}{T_1}}.$$

Equation 4 has been derived on the assumption that the speed of the driven sprocket is constant. The speed is in fact subject to small fluctuations but it may be shown that the error involved in Eq. 4 is negligible.

Equation 4 may be written

$$R_2 \sin\theta_2 \doteq Na_0 + \frac{b_1}{N}\cos pt + \frac{c_1}{N}\sin pt \tag{5}$$

where

$$b_1 = a_1\cos\alpha$$
$$c_1 = a_1\sin\alpha.$$

Let the speed of A_2 be given by

$$-\dot{x}_2 \doteq \frac{n_1}{N}\left\{Na_0 + \frac{l_1}{N}\cos pt + \frac{m_1}{N}\sin pt\right\} \tag{6}$$

where l_1, m_1 are constants to be determined.

Integrating and substituting boundary conditions

$$-x_2 \doteq \frac{n_1}{N}\left\{Na_0 t + \frac{l_1}{pN}\sin pt - \frac{m_1}{pN}\cos pt\right\} + (A + l). \tag{7}$$

Now $\theta_2 \simeq \dfrac{-\dot{x}_2}{R_2 \sin \theta_2}$ and substituting from (5) and (6) and noting that b_1 and c_1 are small quantities we get

$$\theta_2 \simeq \frac{n_1}{N}\left\{1 + \frac{(l_1 - b_1)}{N^2 a_0}\cos pt + \frac{(m_1 - c_1)}{N^2 a_0}\sin pt\right\}.$$

This gives

$$\theta_2 \simeq \frac{n_1 p}{N^2 a_0}\{(m_1 - c_1)\cos pt - (l_1 - b_1)\sin pt\}. \tag{8}$$

For the oscillation of the driven system about its axis of rotation, the equation of motion is

$$I\ddot{\theta}_2 + k(x_1 + l - x_2)R_2 \sin \theta_2 = 0 \tag{9}$$

where I = moment of inertia of driven system about axis of rotation, and k = longitudinal stiffness of chain.

Substituting for $\ddot{\theta}_2$, x_2, x_1 and $R_2 \sin \theta_2$ we get

$$\{p^2(m_1 - c_1) - \omega^2 m_1\}\cos pt + \{\omega^2(l_1 - a_1 N^2) - p^2(l_1 - b_1)\}\sin pt = 0 \tag{10}$$

where $\omega = \left(\dfrac{kN^2 a_0^2}{I}\right)^{\frac{1}{2}}$.

Since this equation is to be satisfied for all t, we get

$$m_1 = \frac{c_1}{1 - \dfrac{\omega^2}{p^2}}$$

and

$$l_1 = \frac{b_1 - a_1 \dfrac{N^2\omega^2}{p^2}}{1 - \dfrac{\omega^2}{p^2}}.$$

Dynamic load in chain $= k(x_1 + l - x_2)$

$$= \frac{k}{T_1}\left\{\left(\frac{l_1}{N^2} - a_1\right)\sin pt - \frac{m_1}{N^2}\cos pt\right\}.$$

Substituting for l_1 and m_1 the maximum dynamic load is given by

$$P = \frac{k}{T_1}\left\{\left(\frac{b_1}{N^2} - a_1\right)^2 + \left(\frac{c_1}{N^2}\right)^2\right\}^{\frac{1}{2}} \frac{1}{1 - \frac{\omega^2}{p^2}}. \tag{11}$$

This shows that the dynamic effect of polygonal action is similar to that of a forced vibration and that large forces may develop when p, the circular frequency of tooth engagement, is equal to ω, the natural circular frequency of the system.

Putting

$$b_1 = a_1 \cos \alpha$$

$$c_1 = a_1 \sin \alpha,$$

we get

$$P \propto \frac{a_1^2}{N^4}\{(\cos \alpha - N^2)^2 + \sin^2 \alpha\}$$

$$\propto \frac{a_1^2}{N^4}(1 - 2N^2 \cos \alpha + N^4).$$

This shows that for a given speed ratio N, the dynamic load P is

(*i*) a minimum when $\alpha = 0$, that is, integral number of pitches in the direct common tangent.

(*ii*) a maximum when $\alpha = \pi$, that is, an odd number of half pitches in the direct common tangent.

As can be expected, the dynamic load is zero when $N = 1$ and $\alpha = 0$, that is, equal sprockets at a distance apart equal to an integral multiple of the pitch.

It is also possible for resonance to occur at half the critical speed, being excited by the second harmonic, but the dynamic load due to this is likely to be small.

A SOLUTION OF THE NON-LINEAR DIFFERENTIAL EQUATION OF THE ROTATING MACHINE OSCILLATOR

BY

C. V. GOVINDA RAO [1]

ABSTRACT

In a previous paper (1)[2] an analysis of the d-c. series generator–separately excited motor oscillator was presented without the solution of non-linear differential equation developed for the analysis. The equation was a modification of the well known Van der Pol equation with an extra term of the fifth degree to account for the discrepancies between the theoretical and experimental results. Analytical solution of the equation seems rather not possible. In this paper a semigraphical and seminumerical solution based on Liénard's Isocline method (2) is presented. Several interesting conclusions have been drawn, some of which agree with the results qualitatively arrived at in the previous paper. The derivation of the basic equation has been added for the sake of completeness.

1. THE EQUATION

Figure 1 shows the essential electro-mechanical circuit in which the following quantities are represented:

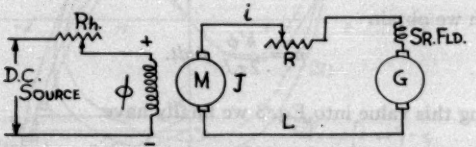

FIG. 1.

L = equivalent linearized inductance of the series circuit,
R = effective resistance of the series circuit,
ϕ = field flux of the separately excited motor,
J = moment of inertia of the oscillator including viscous friction, and
i = instantaneous series circuit current.

At any instant, the series generator voltage is given by (1)

$$e_g = \alpha i + (\beta/3)i^3 - (\gamma/5)i^5 \tag{1}$$

and the back emf. developed by the oscillator by

$$e = k'\phi n \tag{2}$$

[1] Electrical Engineering Department, University of Roorkee, Roorkee, India.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

where α, β, γ and k' are the parametric constants of the set and n the instantaneous speed of the oscillator. Due to the series circuit current i, the voltage drops in the inductance L and resistance R at the instant considered equal $Ri + L(di/dt)$. Then for electrodynamic equilibrium, we have

$$L(di/dt) + Ri + k'\phi n = \alpha i + (\beta/3)i^3 - (\gamma/5)i^5. \tag{3}$$

The stored kinetic energy (K.E.) of the oscillator is given by

$$\text{K.E.} = \tfrac{1}{2}J\omega^2,$$

ω being its angular velocity. Its instantaneous power then is

$$p = J\omega(d\omega/dt). \tag{4}$$

This power must be equal to the electrical power accelerating the rotor. Thus we have

$$e_b i = k'\phi \frac{\omega}{2\pi} i$$

$$= J\omega(d\omega/dt)$$

from which we obtain

$$n = \frac{k'\phi}{2\pi J} \int i dt. \tag{5}$$

Substituting this value into Eq. 3 we finally have

$$L(di/dt) + Ri + k\phi^2 \int i dt = \alpha i + (\beta/3)i^3 - (\gamma/5)i^5 \tag{6}$$

where $k = k'/2\pi J$. Equation 6 is to be further reduced to a suitable form for solution.

2. REDUCTION OF THE EQUATION

If q be the charge in motion at any instant in the series circuit, then $\dot{q}$ is the current i at that instant. Substituting $\dot{q}$ into Eq. 6 and rearranging the terms, we have

$$L\ddot{q} + (R - \alpha)\dot{q} - (\beta/3)\dot{q}^3 + (\gamma/5)\dot{q}^5 + k\phi^2 q = 0. \tag{7}$$

Putting $t = \tau/n_1$ and $n_1^2 = (k\phi^2)/L$ into the above equation, we have

$$\ddot{q} + \frac{R - \alpha}{n_1 L}\dot{q} - \frac{\beta}{3n_1 L}\dot{q}^3 + \frac{\gamma}{5n_1 L}\dot{q}^5 + q = 0. \tag{8}$$

Defining $(R - \alpha)/(n_1 L) = \mu$, and writing $q = i(di/dq)$, Eq. 8 can be reduced to the form

$$i(di/dq) + \mu\{i - ai^3 + bi^5\} + q = 0 \qquad (9)$$

a and b being equal to $\frac{\beta}{3(R-\alpha)}$ and $\frac{\gamma}{5(R-\alpha)}$, respectively.

All physical quantities have been suitably transformed to give the non-dimensional μ in this equation. This is the required form for the graphical analysis.

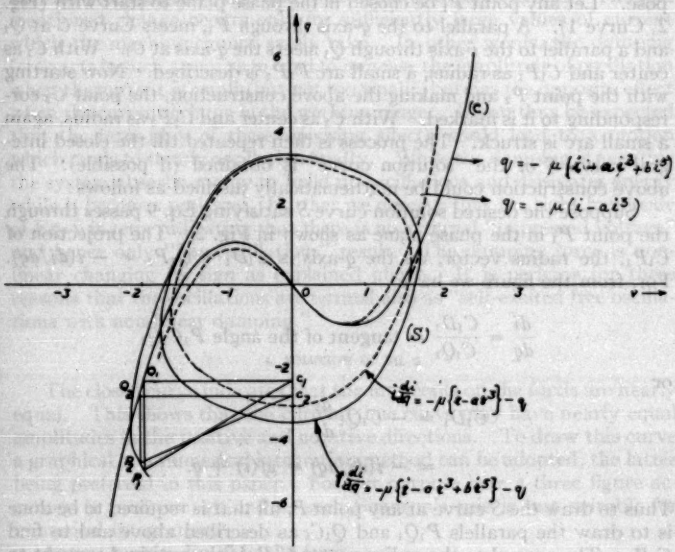

FIG. 2.

3. LIÉNARD CONSTRUCTION

Equation 9 is of the form

$$\frac{di}{dt} = -\frac{\mu f(i) + q}{i}.$$

Following Von Kármán (2) we subject it to the analysis by the method of "isoclines." In particular, Liénard's method is preferred to examine the possibility of periodic solution. To do so it is necessary to plot the

curve satisfying $q + \mu f(i) = 0$ for a finite value of μ and then derive from it the integral curve satisfying Eq. 9. The former is often referred to as the "phase-plane" plot. If the integral curve gives a closed loop or a "limit cycle" agreeing with Poincaré, Eq. 9 admits a periodic solution; otherwise not.

For $\mu = 2$, $\alpha = 16.1$, $\beta = 7.53$, $\gamma = 0.7$, $a = 0.51$ and $b = 0.029$, curve C satisfying $q + \mu f(i) = 0$ is shown in Fig. 2. It is to be noted that for values of $i > 0.8$ and $i < -0.8$ the curve moves away very fast till it again shows a tendency to return. As the working range falls within these limits, the return curve need not be considered for our purpose. Let any point P_1 be chosen in the phase plane to start with (Fig. 2, Curve 1). A parallel to the q-axis through P_1, meets Curve C at Q_1 and a parallel to the i-axis through Q_1 meets the q-axis at C_1. With C_1 as center and C_1P_1 as radius, a small arc P_1P_2 is described. Now starting with the point P_2 and making the above construction, the point C_2 corresponding to it is marked. With C_2 as center and C_2P_2 as radius, again a small arc is struck. The process is then repeated till the closed integral curve S or the "solution curve" is obtained (if possible). The above construction could be mathematically justified as follows:

Suppose the desired solution curve S satisfying Eq. 9 passes through the point P_1 in the phase plane as shown in Fig. 2. The projection of C_1P_1, the radius vector, on the q-axis is $C_1D_1 = Q_1P_1 = -i(di/dq)$. For, from the figure we have

$$\frac{di}{dq} = \frac{C_1D_1}{C_1Q_1} = \text{tangent of the angle } P_1C_1Q_1$$

or

$$C_1D_1 = -C_1Q_1\frac{di}{dq}$$

$$= -i(di/dq) = \mu f(i) + q.$$

Thus to draw the S curve at any point P, all that is required to be done is to draw the parallels P_1Q_1 and Q_1C_1 as described above and to find C_1P_1. The normal to the radius vector C_1P_1 is the required tangent to the curve and if the arcs drawn are sufficiently small, at every point in the plane they represent the proper tangents.

It is interesting to note that the curve spirals inwards as the point P_1 travels in the clockwise direction, finally merging with the limit cycle. With the term bv^5 neglected, the equation could be easily identified with the Van der Pol's equation whose limit cycle is also shown dotted in Fig. 2. It is also interesting to note the difference between the C and S curves of the two cases which explain the discrepancies observed between the theoretical and experimental results when the fifth degree term is neglected. We thus conclude that Eq. 9 admits a

periodic solution for $\mu = 2$ and this period is unique for each set of parametric constants. The limit cycle also indicates that each oscillation corresponds to the movement of the point P_1 once round it and the time required to traverse this loop once, is the period of the oscillation. The very procedure of construction is convincing enough to infer that all motions of the system tend to a single periodic motion, with increasing time, for each set of parameters.

That Eq. 9 admits a periodic solution can also be explained as follows: as μ is greater than zero, for small values of current, the sign of the damping term is positive. This, however, gradually changes its sign first to a negative one and then again to a positive one. The last mentioned change occurs only for sufficiently large values of current which the machine cannot safely take. In other words, the damping force acts in such a way as to tend to increase the amplitude of oscillation when the current is small (but not too small), but has the opposite effect when the current is large in the working range. It can thus be expected that the inter-play of these opposing effects would lead to a motion which tends to steady oscillation finally. While the damping is negative the system absorbs energy to build up oscillations and dissipates energy while it becomes positive. Further we observe that the right hand side of Eq. 9 is zero, indicating that there is no external "impressed voltage" and hence only "free oscillations" result. The damping force is non-linear changing its sign as explained above. It is perhaps for these reasons that the oscillations are termed also as "self-excited free oscillations with non-linear damping."

4. SOLUTION OF EQ. 9

The closed curve indicates that the intercepts on the i-axis are nearly equal. This shows that the current-time curve may have nearly equal amplitudes in the positive and negative directions. To draw this curve a graphical or a numerical integration method can be adopted, the latter being preferred in this paper. For our purpose here a three figure accuracy is good enough and as such Simpson's rule is just suitable for numerical integration.

Let us rewrite Eq. 9 in the form

$$-\frac{di}{\mu(i - ai^3 + bi^5) + q} = \frac{dq}{i}. \tag{10}$$

As we can write down $dq = idt$ and hence $dt = dq/i$, the periodic time $T = \oint (dq/i)$ has to be found by iteration. Therefore, the time required by P_1 to move along a small length of the curve,

$$t_p = \int_{p_1}^{p_2} (dq)/i \tag{11}$$

has to be summed over the entire limit cycle. Thus the values of t_p for suitably chosen limits of integration can be obtained. However, it is to be observed that q vanishes at two points corresponding to the points of intersection of the limit cycle with the q-axis. Under such conditions

TABLE I.

No.	q	i	$1/i$	$t_p = \int_{p_1}^{p_2} (dq)/i$	τ	T
1	0	1.65	0.6075	0.000	0	
2	0.1	1.675	0.597			
3	0.2	1.700	0.589	1.1948	1.1948	—
—	..	..	..	..	..	..

the integration has to be carried out on the left hand member of Eq. 10. The results at intervals of say 0.1 may be tabulated as shown in Table I. The resulting periodic wave of current is shown in Fig. 3 from which we note, as remarked earlier, that the amplitudes in the positive and negative

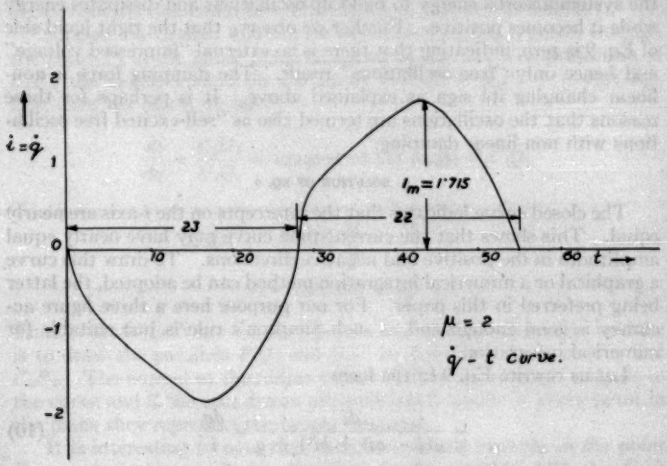

FIG. 3.

directions are not identical and also the two halves of the wave are unequal in area. This evidently proves that the energy fed to the circuit by the generator while the damping is negative is greater than the energy returned by the rotor when it reconverts into electrical energy.

Influence of μ and n_1 on the Performance of the Oscillator

(*a*) μ has profound influence on the behavior of the oscillator. This can be studied by considering various values of it ranging from zero to infinity. Suppose $\mu = 0$, then Eq. 9 degenerates to

$$q + i(di/dq) = 0. \tag{12}$$

The isocline satisfying this equation is a circle given by $i^2 + q^2 =$ a constant, thus giving a perfect sinusoid as periodic solution. On the other hand, if μ becomes very large, the isocline becomes a rectangle with its smaller sides curved. Then the oscillations become very much distorted from the sinusoidal oscillations showing sudden changes in the current to be followed by slow variations. These oscillations are termed "relaxation oscillations." The periodic time characteristically will be larger than for sinusoidal oscillations and depends on μ.

(*b*) The coefficient of charge in Eq. 6 also reveals a very interesting property when we subject it to dimensional analysis. Writing it down from Eq. 5 again, we have

$$\text{coefficient of } q = \frac{k'\phi^2}{2\pi J}. \tag{13}$$

Choosing L, T, I and R for fundamental entities, we have the following:

$$[\phi] = [IRT]$$
$$[J] = [ML^2]$$
$$[M] = (L^{-2}I^2T^2R].$$

As $k'/2\pi$ is dimensionless, on substitution of the above for ϕ^2/J in Eq. 13, we obtain

$$[\phi^2/J] = [I^2R^2T^2][L^2I^{-2}T^{-2}R^{-1}][L^{-2}]$$
$$[\phi^2/J] = [RT^{-1}]. \tag{14}$$

The right hand member of Eq. 14 is the dimensional equivalent of "elastance." If we prefer to consider its inverse, we have

$$[J/\phi^2] = [R^{-1}T] = [C], \tag{15}$$

where C is the "capacitance" of the circuit. In other words, the oscillating rotor in a magnetic field just performs the functions of a condenser in an electric circuit which fact amply justifies the use of "electromechanical capacitance" for the inverse of the coefficient of charge. It represents perhaps a more general type of capacitor than the ordinary condenser used in familiar electric circuits. We have from Eq. 15 that any increase in J has the effect of increasing the capacitance of the

system. On the other hand, any increase of ϕ has the opposite effect. Let us write

$$\mu = (R - \alpha)/n_1 L; \quad n_1^2 L = k\phi^2; \quad \text{and} \quad k\phi^2 = 1/C$$

from which we have

$$\begin{aligned} \mu &= (R - \alpha)/\sqrt{k\phi^2 L} \\ &= (R - \alpha)/\sqrt{(1/C)L} \\ &= k''(R - \alpha)/\sqrt{C/L}. \end{aligned} \tag{16}$$

We see from Eq. 16 that, for given values of R and α, μ varies directly as the square root of C and inversely as the square root of L. As C is proportional to J (Eq. 15), any increase of it by an external means has the tendency to increase μ and thus distort the waveform more and more; an increase of L either by increasing the number of turns or by an external choke, has the effect of bringing down μ and thus making the wave more and more sinusoidal. By a proper control of C and L it is possible to keep μ constant.

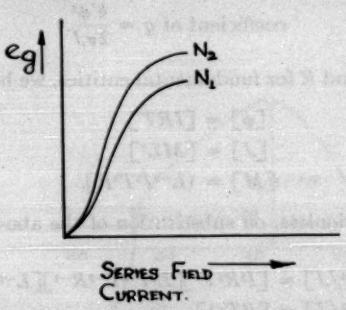

FIG. 4.

If C/L is maintained constant, μ can be varied either by changing R or α. The former is very simple; for any value of external resistance can be introduced into the circuit. But if the resistance exceeds the "critical resistance" of the generator, the voltage does not build up unless the speed of the generator is increased. Under such conditions, as there is not sufficient electrical energy to feed the losses and accelerate the rotor, the machine can only "crawl." This is exactly what happens in the present case. However if the circuit resistance becomes less than the critical value, the machine suddenly bursts into oscillations and after transients die out, it settles down to steady oscillations.

Lastly, when the generator speed is altered, the magnetization curve shifts upwards. For every value of current through the generator the

voltage generated increases in proportion to the increase of speed. Thus if the speed is changed from N_1 to N_2, the voltage corresponding to them being e_{g1} and e_{g2}, we have (Fig. 4)

$$\frac{e_{g1}}{e_{g2}} = \frac{N_1}{N_2} = \frac{\alpha_1 i + (\beta_1/3)i^3 - (\gamma_1/5)i^5}{\alpha_2 i + (\beta_2/3)i^3 - (\gamma_2/5)i^5} = \delta. \tag{17}$$

Therefore, $e_{g1} = e_{g2}\delta$, or $\alpha_1 = \delta\alpha_2$, $\beta_1 = \delta\beta_2$, $\gamma_1 = \delta\gamma_2$ for any value of i. This evidently shows that the parameters α, β, and γ depend on the generator speed. As a result μ also changes as a function of generator speed. A very interesting conclusion can be drawn when $\alpha = R$. If the generator speed is raised gradually, α goes on increasing and at a particular point α equals R in which case the first term of the damping force vanishes. Equation 9 degenerates to

$$i(di/dq) - \mu'\{i^3 - b'i^5\} + q = 0, \tag{18}$$

where $\mu' = \beta/3n_1L$ and $b' = 3\gamma/5\beta = 0.056$. By equating the quantities in the brackets to zero, we have

$$i^3 - 0.056\, i^5 = 0$$

or

$$i = \pm 4.24.$$

Thus for $0 < i < 4.24$, the damping term has a negative value and therefore the machine builds up oscillations absorbing energy from the generator. For $i > 4.24$, as the damping term becomes positive, the system dissipates energy. The oscillator behaves as before but with larger amplitudes. The oscillations will be more sinusoidal in nature.

However, from the above discussion it is clear that μ cannot physically become very large; for neither increase of R nor decrease of field flux of the oscillator indefinitely is practical. As the moment of inertia of the rotor is not zero and there will always be some residual flux in the set, μ can never become zero. Thus it is the case $0 < \mu \ll \infty$ that has any physical significance here.

6. INFLUENCE OF MOTOR FIELD FLUX ON THE PERFORMANCE

We have $n_1^2 = (k\phi^2)/L$ and if we let L be constant in it, we can write $\phi^2/n_1^2 = \text{constant}$. As $1/n_1$ is proportional to periodic-time, we have

$$\phi^2 T^2 = \text{constant, or } \phi T = \text{constant.} \tag{19}$$

This evidently means that the periodic time varies hyperbolically with the field flux which agrees with experimental results. Thus any variation of field flux of the oscillator is always accompanied by a variation of periodic time and therefore depends on n_1 as stated previously.

On the other hand, if ϕ is held constant but the generator speed is

increased, the periodic time also increases. Then the equation $n_1^2 = k\phi^2/L$ should be written as

$$T^2 = \text{constant} \times L. \tag{20}$$

This states that the periodic time varies parabolically with the circuit inductance. At some speed the parameter α may become equal to R as has already been explained, in which case the oscillations become more sinusoidal. This, in effect, is equivalent to an increase in circuit inductance. Thus we see that as far as the circuit is concerned, the effect of increase of generator speed is reflected in an "apparent increase" of its inductance.

Hitherto L has been treated as the linearized value of inductance. Now taking the non-linearity into account, it can be written as a function of current (a very common artifice)

$$L = g - hi^2$$

where g and h are constants. We can write Eq. 20 as

$$g - hi^2 = \theta T^2$$

or

$$hi^2 + \theta T^2 = g, \tag{21}$$

where θ is another constant. Equation 21 represents an ellipse. But the situation is not as simple as is indicated by Eqs. 19, 20, and 21, as μ also has some influence on the periodic time. For values of $\mu < 10$, its influence is not so pronounced and the errors involved in neglecting it will be probably within 5 per cent; hence for comparatively small values of μ, its influence on periodic time may be neglected (4). Thus we see that the generator speed is yet another factor which controls the frequency of oscillations.

7. STABILITY OF OPERATION

Equation 6 on differentiation with respect to t and proper substitutions similar to those used for Eq. 9, can be written as

$$v\frac{dv}{di} + \mu(1 - ci^2 + di^4)v + i = 0 \tag{22}$$

where $v = \dot{q}$, $c = 3a$, and $d = 5b$. Putting $r^2 = v^2 + i^2$ and differentiating with respect to t, we have

$$r\frac{dr}{dt} = v\frac{dv}{dt} + i\frac{di}{dt}$$

or

$$\frac{dr}{dt} = \frac{v}{r}\left\{\frac{dv}{dt} + i\right\}. \tag{23}$$

Inserting the value of dr/dt into Eq. 21 we obtain

$$\frac{dr}{dt} = -\mu \frac{v^2}{r}\{1 - ci^2 + di^4\}$$

$$= \frac{\mu v^2}{r}\{ci^2 - 1 - di^4\}. \tag{24}$$

If $v \neq 0$, μ being positive, dr/dt has the same sign as the quantity in the brackets. Two conclusions can be drawn.

(1) When $ci^2 > (1 + di^4)$, $dr/dt > 0$: r then increases with t. The integral curve S spirals outwards. If the limit cycle exists, the spirals finally merge with it.

(2) When $ci^2 < (1 + di^4)$, $dr/dt < 0$: r decreases with t. The integral curve S spirals inwards. It if starts far away from the origin, it eventually merges with the limit cycle, if it exists.

But when $ci^2 = (1 + di^4)$, the rate of change of r with respect to t is zero indicating r stationary.

Rewriting Eq. 21,

$$\frac{dv}{di} = -\frac{\mu(1 - ci^2 + di^4)v + i}{v}. \tag{25}$$

We observe that $dv/di = 0/0$ when $v = i = 0$. This indeterminate evidently indicates singularity at the origin which has an important bearing on the starting conditions. Thus, near (0,0), we can write Eq. 25 as

$$\frac{dv}{di} = -\frac{\mu v + i}{v}. \tag{26}$$

Following Poincaré, we can define the above as

$$\frac{dv}{di} = \frac{P(i, v)}{Q(i, v)} \tag{27}$$

where $P(i, v) = (\alpha' i + \beta' v)$ and $Q(i, v) = (\gamma' i + \delta' v)$. Comparing Eq. 27 with Eq. 26 we have $\alpha' = -1$, $\beta' = -\mu$, $\gamma' = 0$ and $\delta' = 1$. The characteristic equation for Eq. 27 can be written as (4)

$$\lambda^2 - (\beta' + \gamma')\lambda - (\alpha'\delta' - \beta'\gamma') = 0 \tag{28}$$

from which we have

$$(\beta' + \gamma') = -\mu \tag{29}$$

$$(\alpha'\delta' - \beta'\gamma') = -1 \tag{30}$$

and the determinant of Eq. 27

$$\alpha'\delta' - \beta'\gamma' \neq 0. \tag{31}$$

The roots λ_1, and λ_2 of Eq. 28 are

$$\lambda_1, \lambda_2 = \frac{(\beta' + \gamma') \pm \sqrt{(\beta' - \gamma')^2 + 4\alpha'\delta'}}{2}$$

and are real and unequal if the discriminant $(\beta' - \gamma')^2 + 4\alpha'\delta' > 0$, that is, positive.

Further, we observe determinant $(\alpha'\delta' - \beta'\gamma') = -1$, a negative. λ_1 and λ_2 can be both negative or positive depending on whether $(\beta' + \gamma')$ is negative or positive. If it is the former, a point on the solution curve moves into the singularity as t increases; if the latter, the point moves away from it. In either case the singularity is a nodal point. It was observed during investigations that unless the magnitude of the circuit resistance was reduced below the value of α, the oscillator could only crawl. In one set of experiments, it was found, at a generator speed of 960 rpm., α was 38.7 and the maximum starting resistance was 37 ohms while the maximum resistance which could sustain oscillations, once started, was 56 ohms. Thus, it is an experimental fact that μ is negative during starting, that is, when i is sufficiently small. Therefore, we have $\beta' + \gamma' = -\mu$, a positive quantity, and as the determinant is negative, the singularity is unstable—the point moves away from the origin. Thus, from the disciminant, we have

$$(\beta' - \gamma')^2 + 4\alpha'\delta' = \mu^2 - 4$$

or

$$\mu = \pm 2. \tag{32}$$

For all values of $\mu \geqq 2$, λ_1 and λ_2 are always positive; the singularity will be an unstable node. However, if $(\beta' + \gamma')$ becomes negative, the discriminant is also negative, and the origin is a stable singularity, being a spiral point. This is in complete agreement with the experimental facts.

Again, from

$$\frac{dv}{di} = \frac{\alpha' i + \beta' v}{\gamma' i + \delta' v}$$

we have when $v = 0$,

$$\frac{dv}{di} = \infty. \tag{33}$$

This means that the limit cycle intersects the charge axis orthogonally. On the other hand, when $i = 0$, we have

$$\frac{dv}{di} = \frac{\beta'}{\delta'}$$

which means that the limit cycle intersects the current axis at a slope β'/δ'. These conclusions could be verified from Fig. 3.

When $\mu \ll 1$, as discussed previously, the current wave will be nearly sinusoidal. Under such conditions we can write

$$i = I \sin \omega t. \tag{34}$$

Substituting this into Eq. 3 we obtain

$$RI \sin \omega t + L\omega \cos \omega t - \frac{I}{\omega} k\phi^2 \cos\omega t = \alpha I \sin\omega t + (\beta/3)I^3 \sin^3 \omega t - (\gamma/5)I^5 \sin^5 \omega t. \tag{35}$$

This must hold for all values of t. At $t = 0$, we have

$$\omega LI - \frac{k\phi^2}{\omega} I = 0$$

or

$$\omega^2 = \frac{k\phi^2}{L}. \tag{36}$$

At $\omega t = \pi/2$, $\sin \omega t = 1$, $\cos \omega t = 0$ and thus we have

$$RI = \alpha I + (\beta/3)I^3 - (\gamma/5)I^5$$

or

$$(\gamma/5)I^4 - (\beta/3)I^2 + (R - \alpha) = 0. \tag{37}$$

Equations 36 and 37 could be solved for I and ω.

8. INFLUENCE OF VARIABLE INDUCTANCE AND CAPACITANCE

An oscillogram taken during the investigations indicates the current leads the voltage over one half of the cycle, while it lags over the other half. The behavior is somewhat akin to that observed in a reactance tube. Though the armature reaction of the oscillating motor was neglected for the purpose of analysis, its field flux ϕ cannot be considered to remain constant during the changes. Hence the electromechanical capacitance is not strictly constant and should be considered to depend on the armature reaction. Also, it has been seen that the inductance is a non-linear function of the current. As a consequence of these, there is always an exchange of energy between the inductive and capacitive

parts of the circuit; over a region of the wave the magnetic field predominates and over the other the electric field predominates. While the condenser stores energy, which it does slowly, the current leads the voltage. This will, however, be followed by a quick discharge during which the inductive voltage makes the current lag the generator voltage.

In conclusion, it should be recognized that though apparently simple, the rotating machine oscillator exhibits curiously complex behavior. If the armature reaction and frictional forces are properly taken into account, the solution might become even more difficult and perhaps such a solution might exhibit further interesting properties.

Acknowledgments

The author has pleasure in acknowledging his indebtedness to his colleague, Dr. Chandrika Prasad, Reader in Mathematics, University of Roorkee, who has given him extensive assistance in suggesting the solution and in the preparation of this paper. He is also indebted to Dr. N. G. Shabde, Principal, Vidarbh Maha Vidyalaya, Amravati, for his encouragement and suggestions and to Dr. S. K. Laxman Rao, Dept. of Applied Mathematics, Indian Institute of Science, Bangalore, for useful discussions.

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THE FRANKLIN INSTITUTE AND CENTRAL HIGH SCHOOL IN THEIR EARLY DAYS *

BY

JOSEPH SAMUEL HEPBURN [1]

The Franklin Institute since its founding has played an important part in the educational life of Philadelphia. This paper illustrates one phase of that influence as it relates to the Central High School of Philadelphia.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts was founded at a meeting in the old County Court House (now called Congress Hall) on February 5, 1824 (1),[2] and received a legislative charter on March 30, 1824 (2). The then new Hall of The Franklin Institute (now the Atwater Kent Museum) was occupied in the early spring of 1826 (3). In April of that year the Institute established a high school known as the Franklin High School or the High School of The Franklin Institute (4).

This was the first high school outside of New England and had but one predecessor and one short-lived contemporary in that region (5). Its principal was Walter Rogers Johnson, who had been the principal (now designated head master) of The Public School of Germantown (Germantown Academy) from 1821 to 1826 (6) and became Professor of Chemistry and Natural Philosophy in 1839 in the original faculty of the Medical Department of Pennsylvania (now Gettysburg) College (7, 8). This High School has been referred to as "The predecessor of the Central High School" (9).

When the Institute was founded, the professional schools in Philadelphia were devoted to medicine (University of Pennsylvania, Jefferson Medical College) and pharmacy (Philadelphia College of Pharmacy). Collegiate instruction in applied science lay in the future. The Univer-

* This paper was written as the introduction to the catalogue of exhibits on view in the Barnwell Library of the Central High School of Philadelphia from January 17 to February 8, 1957, and thereafter in the Library of The Franklin Institute. The exhibits were drawn from the Archives of The Franklin Institute, were chiefly holographic manuscripts, and illustrated the close, though informal, relations between the School, its Faculty and Alumni, and the Institute during the early days of both institutions.

Unless otherwise stated, dates have been taken from entries in the manuscript Account Books and Minute Books of The Franklin Institute and Matriculation Book of the Central High School, and from the Yearbook of the Institute for 1928–1929, and the history of the School by Franklin Spencer Edmonds.

[1] Archives Researcher, The Franklin Institute; Historian of The Associated Alumni of The Central High School of Philadelphia.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

sity of Pennsylvania instituted a course in chemistry applied to the arts in 1851 (10), first conferred the degree of Bachelor of Science in 1854 (11), and organized its Towne Scientific School in 1872 (10). The Polytechnic College of the State of Pennsylvania received a legislative charter on April 5, 1853 (12).

The members of the Institute were interested in the suitable education of the younger generation in those fields of knowledge included in its activities, so that that generation would become interested and continue the work begun by the founders. Therefore members of the Institute were active in the effort in 1826 to obtain a legislative charter for a "New College" devoted to the sciences and English literature necessary for a general education. They likewise were active in the effort in 1838 to obtain such a charter for a School of Arts. Both projects were unsuccessful.

Meanwhile, by legislative enactment, the Central High School of Philadelphia had been created on June 13, 1836, for the full education of its pupils (13). From the beginning, close, though informal, relations existed between the School and The Franklin Institute. Two members of the original faculty of the School, John Frost and E. Otis Kendall, became members of the Institute, respectively, in 1830 and 1837. The first principal (now designated president) of the School, from 1839 to 1842, was Alexander Dallas Bache, a great grandson of Benjamin Franklin who had founded the University of Pennsylvania. Bache also served as Superintendent of Public Schools of Philadelphia (1841–1842). He became a member of the Institute in 1829, a life member in 1832, and served it as a manager (1830–1839), corresponding secretary (1840–1844), and chairman of its Committee on Science and the Arts (1834–1836 and 1839–1844).

John Seely Hart, the second president of the School (1842–1858), was elected a member of the Institute in 1843, having been nominated by Bache.

The Controllers of the Public Schools, through their committee on Central High School, exercised jurisdiction over the School. A member of this committee, Andrew Hooton, became a member of the Institute in 1835.

The descendants of William Smith, first provost of the institution now known as the University of Pennsylvania, appear in the early history of both The Franklin Institute and the Central High School. Richard Penn Smith, lawyer, playwright, and former Clerk of the District of the Northern Liberties, was the grandson of William Smith. He became a member of the Institute in 1824, and was Secretary of the Controllers (1838–1841). His son, Horace Wemyss Smith, was a member of the first class to enter the School (14).

Samuel Vaughan Merrick, the founder of The Franklin Institute (15) and its second president (1842–1854), sent two sons to the School.

John Vaughan Merrick was a member of the first class (14) graduated from its "principal course," and was advanced to its degree of Master of Arts[3] in 1850 (16). William H. Merrick entered the School with its twelfth class in 1844, and graduated in 1848 (14, 16). Both sons became partners of their father in the Southwark Foundry.

Under Bache the principal course (18) included modern languages, mathematics, the sciences (physical, natural, political, and moral), history, English literature, writing, and drawing. In his words (19) it "took a ground different from that which they [colleges] occupied." This was the type of institution which the members of The Franklin Institute had in mind in their "New College" and "School of Arts." The Central High School was evaluated in a report by John Fries Frazer[4] on June 17, 1848, as chairman of the Institute's Committee on Instruction:

> When however the Government...established the present common school system, the schools of the Institute became comparatively useless and were abandoned,.... Now it is probable that, so long as the present admirable system of public schools is maintained, and especially while the High School is preserved in the admirable efficiency in preparing its pupils for the duties of active life, which its first Principal gave to it, there will ever[5] again be a necessity for reestablishing the primary schools of the Institute.

The kindly interest taken by The Franklin Institute in the alumni of the Central High School during its early years is revealed by the following gracious episode (20).

At a stated meeting of the Board of Managers of the Institute on March 17, 1847, Samuel V. Merrick "suggested the propriety of admitting the Alumni of the Central High School of Philadelphia to participate in the advantages of the Franklin Institute." After an informal conversation on the subject, it was on motion of Mr. Merrick: "Resolved that the suggestion made to admit the Alumni of the High School to the privileges of the Institute be referred to a Committee of five to report."

The committee consisted of Messrs. Merrick, Fraley, Frazer, Roberts, Agnew.

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[3] The Central High School was granted the power of a university to confer degrees by an Act of Assembly approved April 9, 1849 (17).

[4] John Fries Frazer was especially qualified to evaluate the work and accomplishments of the Central High School since he had served as a member of its Faculty. He had been a pupil of Alexander Dallas Bache at the University of Pennsylvania, was professor of chemistry and natural philosophy in the Central High School 1842–1844, succeeded Bache in the same professorship at the University in 1844 and held it until his death in 1872, serving also as vice-provost 1855–1868, and as acting provost 1859–1860. He became a member of The Franklin Institute in 1835, a life member in 1836, and served it as a Manager in 1844, Corresponding Secretary 1845–1847, Treasurer 1848–1864, Vice-President 1865–1866, editor of its JOURNAL 1850–1866.

[5] In this manuscript report, Frazer apparently intended to write "never," but, by a *lapsus calami*, actually wrote "ever."

At their next meeting, on April 21, 1847, the Managers received a report from this Committee with four appended resolutions which were discussed, amended, and then adopted. The report stated concerning the Alumni of the High School, "They seem the most appropriate connection between our body and the workshops of the country," and also, "They will in fact become our adopted children, succeed to our inheritance, and, we trust, carry our Institute with honor to coming generations. We will through their organization as a permanent branch of the public education in our country reach all classes of the community."

The first resolution was:

> Resolved, that the members of the Alumni Association of the Philadelphia Central High School be and they are hereby admitted to all the privileges of the Franklin Institute, except voting at the meetings of the Institute, or its Committees, until they arrive at the age of twenty-one years—provided they conform to the rules and regulations of the Institute.

The second and third resolutions set forth the procedure for carrying out the terms of the first resolution.

The fourth resolution read:

> Resolved that a copy of the foregoing resolutions be transmitted by the Corresponding Secretary to the President of the Alumni Association of the High School with a request that he shall convene the Association and submit them.[6]

The reply of the Alumni Association which has been preserved in the Archives of The Franklin Institute, read:

> Philadelphia, August 3rd, 1847
>
> Dear Sir:
>
> In pursuance of a resolution passed at a stated meeting of the Alumni Association of the Central High School, held July 22nd, 1847, appointing the undersigned a committee to reply to the Communication of the Franklin Institute read before that meeting, it becomes their duty and they hereby do communicate to the Franklin Institute the high sense entertained by the members of the Alumni Association

[6] On September 15, 1847, the Board of Managers adopted regulations (20) which required exhibition of a Certificate of Membership in the Alumni Association as a prerequisite for enrollment for the privileges of membership in the Institute and which regulated the use of the Library of the Institute by such enrolled members. The Archives of The Franklin Institute contain one of these Certificates. It is dated February 16, 1853, numbered 720, certifies "that Henry E. Hayward is a Member of the Alumni Association of the Central High School of Philadelphia," and is signed by Fred[eric]k [Gottlieb] Heyer, President, and Dan[ie]l W[aldo] Howard, Recording Secretary.

of the honor thus conferred upon them, and their grateful acceptance of the same; and in begging you to lay this reply before the Board of Managers of the Franklin Institute.

They have the honor to remain

Yours respectfully,

John V. Merrick Chmn
John W. Torrey } Committee
J. M. Vanderveer

John F. Frazer, Esq.,
Sec. Franklin Inst.

This Alumni Association had been formed under the guidance of Alexander Dallas Bache on the first commencement day, July 15, 1842, (19, 21) and was incorporated as The Associated Alumni of the Central High School of Philadelphia by a supreme court charter recorded on April 7, 1873 (22). As to the committee men, Merrick (the son of Samuel V. Merrick) became a mechanical engineer, a life member of The Franklin Institute in 1849, and its fifth president, 1867–1869. Torrey (23) was elected a member of the Institute in 1850, and became vice-president of the Corn Exchange National Bank; Vanderveer became an attorney-at-law.

The privileges thus granted to alumni over a century ago have their counterpart in those privileges enjoyed today by such undergraduates and eligible younger alumni of the School as become Student Members of the Institute.

The plan of Samuel V. Merrick and his colleagues was highly successful. The Alumni and/or Faculty of the Central High School have given to The Franklin Institute three presidents (Charles H. Banes, John C. Cresson, and John Vaughan Merrick), several secretaries, several treasurers, over a score of managers, and numerous members. The two institutions, at times, have pooled their equipment for the advancement of science and sound learning. When Jacob F. Holt of the School's Faculty delivered a series of lectures on Hygiene before the Institute in 1872, the announcement read: "The lectures will be amply illustrated from the large collections of the Central High School" (24). The Archives of the Institute contain a letter, written to its Secretary on January 29, 1883, by George I. Riché, fourth president of the School (1866–1886), in which Riché stated: "It will give me pleasure to approve the loan of apparatus requested, although against our usual practice." Another letter in the Archives (dated Central High School, November 7, 1884) was written by Edwin J. Houston to William D. Marks, general superintendent of the Institute's International Electrical Exhibition, concerning apparatus belonging to the School and used at that exhibition.

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(17) *Laws of the General Assembly of the Commonwealth of Pennsylvania*, Session of 1849, pp. 527–528.
(18) FRANKLIN SPENCER EDMONDS, "History of the Central High School of Philadelphia," Philadelphia, J. B. Lippincott Company, 1902, p. 62.
(19) "Address of Prof. A. D. Bache, before the Alumni Association of the Central High School, delivered February 10, 1859," brochure, 8 pages.
(20) FRANKLIN INSTITUTE, Minutes of Board of Managers, Book B, pp. 424–427, 433 (1847).
(21) Minute Book, Board of Professors of the Central High School, July 15, 1842.
(22) Commonwealth of Pennsylvania, Department of State, Bureau of Corporations, Charter Book Volume 8, pp. 465–468.
(23) RICHARD L. AUSTIN AND JOHN L. HANEY, *Barnwell Bulletin*, Vol. 15, no. 61, pp. 29–30 (1938).
(24) "Announcement of The Franklin Institute and Synopsis of Lectures for 1872–73," p. 3.

THE FRANKLIN INSTITUTE

MINUTES OF THE STATED MEETING

December 18, 1957

The Stated Meeting of The Franklin Institute was held at 8:15 P.M. in the Lecture Hall. Dr. S. Wyman Rolph, President, called the meeting to order with approximately 200 members and guests in attendance, among whom were members of the World Affairs Council of Philadelphia.

The President announced that the minutes of the Stated Meeting of October 16, 1957 were printed in the November issue of the JOURNAL OF THE FRANKLIN INSTITUTE. There being no corrections or additions, the minutes were approved as published. The President announced that the minutes of the Stated Meeting of November 20, 1957 will be printed in the December issue of the JOURNAL and will be submitted for approval at the next meeting.

The President announced the Secretary of The Franklin Institute had reported that the following nominations for election to our Board of Managers had been made in conformity with Article IV, Section 5, of our By-Laws:

Henry B. Bryans	Morton Gibbons-Neff
Francis J. Chesterman	Gaylord P. Harnwell
James Creese	Harold S. LeDuc
Rupen Eksergian	W. Laurence LePage
W. H. Fulweiler	Emery W. Loomis

The President then called for nominations from the floor. There being none, the nominations were declared closed.

The President appointed the following members of The Institute, who are neither officers nor nominees, to act as Tellers of the Election: Dr. George S. Crampton, Dr. Joseph S. Hepburn and Mr. Howard Stoertz.

In introducing the speaker of the evening, Colonel Richard S. Leghorn, U.S.A.F. Reserve, who is Chairman of the Special Project Committee on Security through Arms Control of the National Planning Association, the President noted that this Association is one of the citizen groups which assemble to discuss the problems of our democracy and its position in the community of nations.

Colonel Leghorn's talk on "Science and a Rational World Security System" presented a preview of a study being conducted by the N.P.A. to examine the problem of security in this age of technological contests, and presented the problem of enlisting a substantial scientific effort in the construction of a rational world security system. His talk was well received and there followed an interesting discussion period.

The meeting was adjourned by the President at 9:10 P.M.

W. F. JACKSON, JR.
Secretary

MEMBERSHIP

GOLD MEMBERS FOR 1957 HONORED

On November 20, 1957, the Institute paid tribute to two members who had completed fifty years of continuous membership during 1957. Both new Gold Members are children of Dr. Walton Clark, who was a man with an intense interest in The Franklin Institute, serving on its Board of Managers and as President (from 1907 to 1924). Dr. Clark, in 1907, presented two of his children—Darthela and Frank—with Life Memberships in the Institute. This started a family custom which he continued with his other children later on.

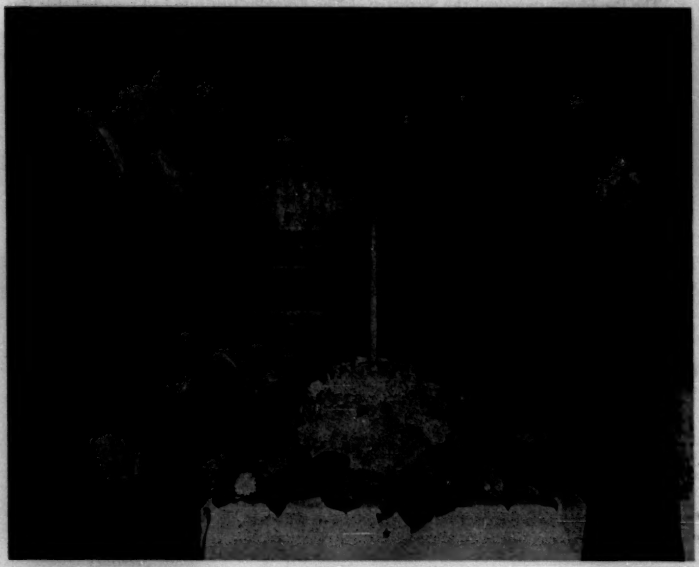
During the dinner which preceded the regular Institute meeting, Miss Darthela Clark was introduced by Dr. S. Wyman Rolph, President, and, with the aid of Mr. Morton Gibbons-Neff, Chairman of the Membership Committee, cut the first slice of an anniversary cake to commemorate her fifty years with the Institute.

During the Stated Meeting, Dr. Rolph presented keys and gold membership cards to Miss Clark, one set for herself and one for her brother, who lives in California and couldn't be present for the ceremonies. Dr. Rolph noted that Miss Clark is the first woman to become a Gold Member.

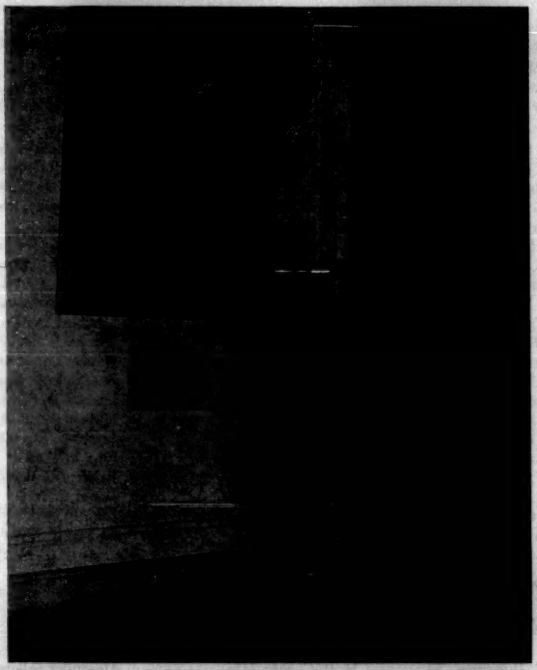
BIOGRAPHICAL SKETCHES OF NEW GOLD MEMBERS

DARTHELA CLARK

Born in Chestnut Hill, Pennsylvania, Darthela Clark was graduated from Bryn Mawr College with an A.B. degree. For more than 20 years, she served as a member of the Board of



Miss Clark, new Gold Member, cuts anniversary cake while Dr. Rolph and Mr. Gibbons-Neff stand by.



Miss Darthela Clark admires the Institute's portrait of her father, Dr. Walton Clark, former President of the Institute. Looking on are Dr. John S. Burlew (left), Executive Vice President, and W. F. Jackson, Jr., Secretary.

Directors of the Pennsylvania School of Horticulture for Women in Ambler. Miss Clark, at present, resides in Chalfont, Pennsylvania.

FRANK SHAW CLARK

Frank Shaw Clark, a native of New Orleans, Louisiana, attended the Episcopal Academy; Pennsylvania Military College, Chester, where he was graduated with a C.E. degree in 1901; and the University of Pennsylvania, where he received his B.S. in Mechanical Engineering in 1904.

After working for eight years in power station construction for various transportation systems in Ohio, Mr. Clark moved to Boston, where he worked as Mechanical Engineer in charge of designing power stations and industrial plants for the Stone & Webster Engineering Corporation. In 1919, he became Chief Mechanical Engineer in charge of all mechanical engineering, and, in 1926, he was made Consulting Engineer, a position which, in addition to mechanical design, included examinations of public utility systems in regard to management, operation, maintenance, forecasts of growth and provision of facilities to meet future needs.

Author of numerous technical articles, Mr. Clark is a Fellow in the American Society of Mechanical Engineers, a member of the Edison Electric Institute and the Association of Edison Illuminating Companies.

Mr. Clark retired in 1951 and presently is living in South Pasadena, California.

NEW MEMBERS

The following elections were approved on December 4, 1957 by the Membership Committee by authority given to it by the Board of Management.

LIFE MEMBERSHIP

H. Perry L. Harrison

David Barnard Steinman

ANNUAL

Ellwood C. Barras
William J. Beckfield, M.D.
David Berger
Albert G. Blank
Helmuth G. Braendel
William S. Buckley
Frank C. Burk
Joseph Busel
J. Ebert Butterworth
Alfred Cadet
Patrick F. Cagney
Kenneth O. Cale
Joseph C. Carfagno
G. Rayner Carrick
Edward A. Carson
Edward W. Carson
Rocco Casciato
Robert J. Casey
Alfred B. Cawthorne, Sr.
John R. Chamberlin, Jr.
Shurman Y. Chang
S. A. Chopko
Albert B. Clark, Jr.
Cecil L. Clark
Arthur Edward Clarke, Jr.
I. A. Clarke
Walter E. Clarke
Luke E. Closson
William J. Clothier, II
William H. Coleman
Walter F. Coles, Jr.
Robert T. Connors
Harris Lee Cooperman
H. W. Cornelius, Jr.
Walter H. Corson, II
William Coyne
W. Howard Dilks, Jr.
R. J. Doherty
Robert H. Eckert
William H. Forster
Chester Coleman Gutner
J. Burton Henry
Robert P. Hooper III
Charles H. Horn
I. M. Levitt, Ph.D.
Sidney Levy
Laurence H. Lucker, Jr.
Frederick J. Olsson
David A. Partridge
C. V. Prestowitz
Lambert Ott Pursell
Stanley S. Sagan
Robert Loran Smith
Benjamin V. Spalding
Donald R. Sparks
Hubert B. Stallings
James C. Stretch
Max M. Tall
Robert W. Watson
James L. Wolf
John R. Wolfe
George R. Yake

EDUCATOR

B. Elizabeth Beatty, D.D.S.
Edward L. Burkhardt
William J. Rice

NON-RESIDENT

Chester A. Grondzik
Peter B. Roll

NECROLOGY

Sidney C. Burgoyne, '53
Mrs. Howard Butcher, '38
H. P. Conner, '37
Isaac Harter, '29
Carl A. Schafer, '54
Alexander Sellers, '54
Ludwig Wasum, '34

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, December 11, 1957.)

HALL OF THE COMMITTEE,
PHILADELPHIA, DECEMBER 11, 1957.

MR. JOHN H. NEHER in the Chair.

The following report was presented for final action:

No. 3297: Work of James Bailey
in the Field of Extruding Plastics.

This report recommended the award of an Edward Longstreth Medal to James Bailey, of West Hartford, Connecticut, "In consideration of the many advances in the art of processing plastics based on his personal technical contributions and his effective leadership in research and development, and particularly of the development under his direction of methods for the successful commercial manufacture of unbreakable plastic bottles."

D. S. FAHRNEY,
Secretary to Committee

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor. 136 items have been added the past month.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A.M. until 5 P.M. on Mondays, Tuesdays, Thursdays, Fridays and Saturdays; and 2 P.M. until 10 P.M. on Wednesdays.

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We shall be glad to supply any additional information regarding gifts and memorials. Please write to the above address, attention of the Secretary.

VISIT OF EUROPEAN SCIENTISTS AND ENGINEERS

Sponsored by European Productivity Agency

A group of European scientists and engineers interested in materials testing spent Saturday, November 23, at The Franklin Institute. In addition to guided tours of the Laboratories and the Museum, they visited the Library and the Planetarium. The Institute was glad to participate in the program to strengthen the ties between Europe and America.

The visitors, whose names and affiliations are listed below, were members of Mission No. 388 of the European Productivity Agency.

Name	Firm	Position
Denmark		
Svend Aage Lund	Svejsecentralen (Welding Institution)	Chief Engineer
Hans Christian Vinter	Svejsecentralen	Director
France		
Maurice Armand Aubry	Laboratoire National D'Essais	Head of Metallurgical Dept.
Jean Roger Barbaud	Federation des Industries Mecaniques et Transformatrices des Metaux	Engineer in Charge of Training of Lab. Personnel
M. Chateau	Regie Nationale des Usines Renault	Head of General Scientific Research
Paul Eugene Dangelzer	Compagnie Francaise des Metaux	Assistant Head of Plant Development
Paul M. Dedieu	Societé Francaise Radio-electrique	Head of Purchasing & Inspection Dept.
Maxime Louis Jentet	Societé des Usines Chausson	Manager of Quality Control Dept.
Jacques Edmond Marty	S.A. Automobiles Peugeot	Metallurgical Engineer Head of Testing Lab.
Michel Maurice Renout	S.I.M.C.A. (Metallurgy)	Director of the Testing & Research Dept.
Germany		
Max Richard Hempel	Max-Planck-Institute for Iron Research	Head of Lab. & Member of Scientific Staff
Kurt Nagel	Badische Anilin- & Soda-Fabrik AG	Plant Engineer and Staff Engineer, Materials Testing Div.
Hans Willi Paffrath	Farbenfabriken Bayer AG	Physicist. Chief, Plastics Testing
Karl Ruhl	Materialprufund (Federal Institute for Testing Material)	Head of Dept. for Testing of Building Materials
Hans Eberhard Sigwart	Daimler-Benz Aktiengesellschaft	Chief of Materials Testing Dept.
Italy		
Gianni Castorani	Sicedison S.P.A.	Technical Office Engineer
Salvatore Cuomo	Direzione Generale dei Servizi Antincendi (Ministry of the Interior)	Asst. to Laboratory of Strength of Materials
Oscar Masi	Fiat-Steel Division	Asst. to the General Manager, Steel Division

Name	Firm	Position
Giulio Cesare Soncini	National Natural Gas Pipeline Co.	Officer of Training in Personnel Dept.
Toniolo Bruno	Sicedison	Assistant Manager and Control Maintenance Installations
Norway		
Sverre Asbjorn Markestad	Norwegian Institute of Technology	Professor
Sweden		
Solve Carlen	Aktiebolaget Scenska Metallverken	Chief of Control Dept.
Lennart Hans Soderberg	AB Svenska Metallverken	Head, Department Quality Control
Ivar Weibull	Saab Aircraft Co.	Head, Materials Lab.
United Kingdom		
Arthur Binns	W & T Avery Ltd.	Chartered Mechanical Engineer
Edwin Garnet Stanford	Aluminium Laboratories Ltd.	Head of Physics Div.
Alexander Rankin	Kelvin & Hughes, Ltd.	Senior Research Engineer
	.....	
C. S. Du Mont	Battelle Memorial Institute	In Charge of Tour

THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, FOUNDER
WILLIAM G. BATT, DIRECTOR

THE ANTI-TUMOR ACTIVITIES *IN VITRO* OF 5-IMINO-1,2,4-DITHIAZOLIDIN-3-THIONE AND BIS(DIETHYLTHIOCARBAMOYL) DISULFIDE TOWARD THE KREBS-2 ASCITES CARCINOMA

BY

FRANCIS E. REINHART, S. J. DE COURCY, JR., AND WILLIAM G. BATT

ABSTRACT

Krebs-2 ascites carcinoma cells suspended in modified Hanks' salt solution were exposed aerobically for a three-hour period of incubation at 37° C. to low concentrations (2.5 to 10 μg. per ml.) of 5-imino-1,2,4-dithiazolidin-3-thione (IDT), the 5-acetyl derivative of the latter, and bis(diethylthiocarbamoyl)disulfide (antabuse). Cell injury as evidenced by bleb formation was observed with IDT and antabuse; in addition, the latter at 10 μg./ml. caused 100 per cent loss of viability as indicated by the eosin staining technique.

Cell injury by the two agents was not evident when they were tested in the presence of reduced glutathione or of glucose.

INTRODUCTION

The screening *in vitro* of various sulfur-containing organic compounds for anti-tumor activity with respect to the Krebs-2 ascites carcinoma is being carried out in this Laboratory. As a part of the study, observations have been made on the action of some of these compounds on washed tumor cells suspended in an isotonic salt medium under aerobic conditions. The behavior noted with two of these compounds, 5-imino-1,2,4-dithiazolidin-3-thione (IDT) [isoperthiocyanic acid; xanthane hydride] and bis (diethylthiocarbamoyl)disulfide (antabuse), used alone as well as in the presence of reduced glutathione and of glucose, will be discussed here. Included also are observations on the 5-acetyl derivative of IDT.

MATERIALS AND METHODS

5-Imino-1,2,4-dithiazolidin-3-thione (IDT) was prepared according to Chattaway and Stevens (1). Antabuse, a commercial sample kindly supplied by Sharples Chemicals, Inc., was prepared for testing by two recrystallizations from isopropyl alcohol. The acetyl derivative of IDT was obtained by the method of Nencki and Leppert (2).

The Krebs-2 ascites tumor has been carried in this Laboratory for several years by weekly transfer in female Swiss albino mice.

Solutions of the compounds were made up at a concentration of 100 μg. per ml. in 95 per cent ethanol. Aliquot portions of these solutions, based on a final volume of 2 ml. per flask, were added to 25 ml. Erlenmeyer flasks so as to obtain a duplicate series of graded concentrations of the compound. Two control flasks, into which 0.3 ml. of

ethanol was introduced were included. The solvent was evaporated *in vacuo* from all flasks after which each flask received 1.5 ml. of a modified Hanks' balanced salt solution (NaCl, 8.0; KCl, 0.40; $MgSO_4.7\ H_2O$, 0.20; Na_2HPO_4, 0.048; KH_2PO_4, 0.06; $CaCl_2$, 0.14; and $NaHCO_3$, 0.06 in grams per liter distilled water). All flasks were then stoppered with non-absorbent cotton, placed on a mechanical shaking apparatus, and gently agitated for a period of 1 hr. at 37° C. to insure solution of the test compounds.

During this one-hour period, a tumor cell suspension was prepared at room temperature as follows: a female Swiss albino mouse bearing a 7 or 8 day Krebs-2 ascites carcinoma was sacrificed by decapitation and 3 ml. of cell-containing ascitic fluid were withdrawn. The sample was lightly centrifuged (300 × *g* for 4 min.) to separate the ascitic fluid, which was discarded. The sample was reconstituted to original volume with salt solution and recentrifuged. This washing procedure was repeated twice. A sample (1 to 2 ml.) of the final reconstituted cell suspension was diluted approximately 15 times with the salt solution. One-half ml. of this unadjusted cell suspension was removed, further diluted 3:1 for ease of counting and the cell concentration of the sample accurately determined by direct count in a hemocytometer. Further

TABLE I.—*Action of Several Sulfur-Containing Compounds on Krebs-2 Ascites Carcinoma Cells.*

Compound	Final Conc. μg./ml.	Addition	Final Conc. μg./ml.	Generalized Cell Injury*	No. of Expts.
None		None		—	5
IDT	10			+++	5
IDT	5			+++	5
IDT	2.5			++	3
IDT	1.0			—	3
IDT	5	GSH	50	—	2
IDT	5	GSH	25	—	2
IDT	5	GSH	10	—	2
IDT	5	GSH	5	+	2
IDT	5	GSH	1	++	2
IDT	5	Glucose	200	—	2
		Glucose	200	—	2
		GSH	50	—	2
Antabuse	10			**	6
Antabuse	5			+++	6
Antabuse	2.5			—	2
Antabuse	1.0			—	2
Antabuse	10	GSH	25	—	2
Antabuse	5	GSH	50	—	2
Antabuse	5	GSH	25	—	2
Antabuse	5	GSH	10	—	2
Antabuse	5	GSH	5	—	2
Antabuse	5	GSH	1	++	2
Antabuse	5	Glucose	200	—	2
5-Acetimino-1,2,4-dithiazolidin-3-thione	10			—	2
	5			—	2

* — None evident.
\+ Incipient bleb formation.
++ Severe bleb formation.
+++ Extensive bleb formation with liberation of numerous (lipid?) droplets.
** 100 per cent of cells stained by eosin.

dilution of the stock cell suspension was then made to give a final adjusted concentration of 5.2×10^6 cells per ml. (All operations concerned with the preparation of the cell suspension were carried out with no special regard to sterility.)

The flasks were removed from the shaking apparatus following the one-hour period of agitation in the absence of cells, and placed in the dark in order to eliminate any possible light effects. At ten-minute intervals one-half ml. of adjusted cell suspension was added to each flask of a pair. The flasks were then placed on the shaking apparatus and agitated at 37° C. for exactly 3 hr. Initial and final pH values during the course of a run were found to lie in the range of 7.0–7.3. In experiments where glucose was added, lower pH values, due to glucolysis, were encountered.

After the 3-hr. incubation period, a small sample (0.2 ml.) was taken, mixed with 0.1 ml. of eosin stain (1:2000 in salt solution) and observed microscopically (high-dry) in a hemocytometer. The percentage of eosin-stained cells in a total of 200 cells was determined; eosin staining was considered as presumptive evidence of loss of cell viability (3, 4). At the same time, observations of gross cell injury as indicated by bleb formation were made. An arbitrary system of grading was used (Table I).

RESULTS

Tumor cells exposed for 3 hr. to 5 or 10 μg./ml. of IDT or antabuse suffered severe injury as evidenced by generalized bleb formation (Table I). At the same concentrations, the acetyl derivative of the former compound is seen to be inactive. No visible evidence of injury was observed in untreated cells; staining by eosin did not exceed 2 per cent. Eosin staining above the 2 per cent control value was not observed in treated cells except with antabuse at 10 μg./ml., where staining of 100 per cent of the cells was consistently noted. This superior activity of antabuse as compared with that displayed by IDT at 10 μg./ml. becomes more evident when the respective molar concentrations are considered, equal concentrations of the two substances by weight corresponding to a 1:2 ratio of molar concentrations of antabuse to IDT.

Gross cell injury due to these two substances does not appear when each is tested in the presence of relatively low concentrations of reduced glutathione (GSH) (Table I). This effect was observed when the GSH was added one hour before or at the time of addition of cells. With respect to the effect of GSH on the activity of antabuse, reversal of the enzyme-inhibitory properties of the latter by GSH or cysteine has been reported in studies made with several aldehyde-oxidizing enzyme systems (5, 6) and on yeast fermentation (7). In the case of the inhibition of activity of D-glyceraldehyde 3-phosphate dehydrogenase by antabuse, it had been suggested (6) that interference with essential SH

groups was concerned. Johnston (8) later noted that antabuse and several closely related thiuram disulfides are easily reduced by GSH at pH 7.2 and thus may inhibit the dehydrogenase by oxidizing the glutathione prosthetic group.

As a result of several tests, reactivity toward GSH similar to that reported for antabuse has been found for IDT. Paper chromatography (ascending method, water-saturated n-butanol as solvent) was utilized and visualization of spots was effected by exposure of the dried developed chromatogram to iodine vapor. Under these conditions the pure IDT had $R_f = .82$ and appeared as a fairly stable yellow spot on exposure to iodine. Amounts of the order of 10 μg. were easily detected in this manner.

Reaction of the compound with GSH in the absence of buffer caused appearance of hydrogen sulfide (detected with lead acetate test paper) as well as thiourea ($R_f = .36$, yellow with iodine). However, when 500 μg./ml. suspensions of the compound in M/50 phosphate buffer (pH 7.0) with and without the addition of GSH (200 μg./ml., neutralized) were shaken at 37° C. for 4 hr. the following observations were made: the compound was dissolved only slightly in the simple buffer with no evidence of hydrogen sulfide formation. Complete solution, however, was effected in the GSH-containing sample, hydrogen sulfide was evolved and only a trace of the original IDT could be detected on the chromatogram. The latter showed the presence of an unidentified product giving a relatively dense spot (yellow with iodine, negative to ninhydrin) at $R_f = .17$. Although oxidation-reduction is probably involved here, further work will be required for elucidation of the reaction.

The above discussed analogies in the behavior of IDT and antabuse toward GSH in buffered solution as well as toward the Krebs-2 cell in the presence or absence of GSH have been extended by observation of the action of each compound on tumor cells in the presence of glucose (Table I). Here it is noted that 200 μg./ml. levels of the latter substance entirely prevent the severe toxic effects of 5 μg./ml. concentrations of each agent.[1] With respect to the nature of this reversal, consideration is being given to the lowered pH values (as compared to that of control suspensions) due to glucolysis and to the possibility that the reduced triphosphopyridine nucleotide-dependent glutathione reductase system, which has been shown to be present in ascites tumor cells (9), may be concerned.

These analogies in behavior of the two agents make it appear probable that their effects on the Krebs-2 tumor cell observed in these experiments are brought about by a common mechanism. This would

[1] At higher concentrations each agent had been found to inhibit anaerobic glucolysis of Krebs-2 ascites cells. See W. D. YUSHOK, *Cancer Research*, Supplement (in press).

be expected also because of the close chemical relationship which they bear to each other. That such a mechanism may be mainly based on an interference with vital SH centers in the tumor cell seems logical in the light of previously reported observations on the enzyme-inhibitory actions of one of the agents, antabuse, as well as observations recorded here relating to the behavior of each agent in the presence or absence of glutathione.

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THE FRANKLIN INSTITUTE MUSEUM
A. C. CARLTON, DIRECTOR

PULP AND PAPER MAKING

BY

THOMAS COULSON[1]

The average person buys so little paper directly that he does not realize the size and scope of the paper industry. Paper is money, letters, postage stamps, books, household tissues, newspapers, blue prints, food packaging, wrappings, and checks, and a host of other things in daily use. The per capita consumption of paper in the United States is about 400 pounds. It is not surprising then that pulp, paper, and board mills rank fifth in the terms of value of their products, being exceeded only by motor vehicles and parts, wholesale meat packing, steel and rolling mills, and petroleum refining.

In order that the papermaking section of the Museum might be fully representative of this vast industry, a special room has now been designed with the co-operation of the Middle Atlantic Group of the American Paper and Pulp Association.

When paper was first developed it was made exclusively of linen rags but, as its use expanded, the supply of the raw material proved totally inadequate to meet the demands. This promoted a search for a substitute, and many vegetable substances, such as grass and straw, were investigated before it was found that the cellulose in wood gave excellent results.

The latest available figures show that over 29 million cords of wood are consumed annually in the pulp mills. With such a gigantic consumption there would appear to be a dismal future for our forests. Actually, there is no need for pessimism, for the industry is applying a far-seeing policy of conservation. Through the application of advanced views on forestry, the nation's forests may be regarded as a continuing natural resource. Pulp mill owners are acquiring their own forests, and are striving, with happy results, toward securing a succession of tree crops, thus guaranteeing a sustained yield.

The exhibit in the Museum opens with a brief survey of this activity and proceeds with the story of the combination of wood, labor, water, and energy which culminates in the production of paper of all kinds. An attractive background to the whole story of the paper industry has been designed with the object of presenting the visitor with a comprehensive view. Provision has been made for those who want more detail, such as flow charts for the three main chemical processes.

Until the early years of the 19th Century, all paper was made in single sheets by hand, a slow and laborious process as may be seen from the exhibit. The increasing demand for more and more paper of

[1] Director of Museum Research.

all kinds promoted the mechanization of production, so that machines now turn out paper in a continuous roll which can be cut to convenient sizes, often cut before it leaves the machine.

The high point of the display is the operation at scheduled times of the scale-model Foudrinier papermaking machine. Small as this machine may be, it makes paper. It is not generally known that this little machine has been used to run a variety of experiments in which the most unlikely materials have been incorporated, fiberglas, artificial fibers, rubber,—even a high explosive. One of the most difficult problems was to make a paper thinner than cigarette paper, an experiment which required use of a special wire. Industrial firms have found that their experiments may be run most economically on this machine.

Passing from the actual process of papermaking, visitors will have the opportunity of seeing how tests are applied to ensure that the paper meets with specifications, and also the variety of papers now in use. Some of the uses to which paper is used will be shown in exhibits that will be changed at intervals in order to present the wide diversity of uses.

Paper has been used as a substitute for many other materials, but no substitute has yet been found for paper. This Museum exhibit will serve as an excellent introduction to a subject that influences all our lives. Try to imagine how a modern business could be conducted without paper.

THE FRANKLIN INSTITUTE LABORATORIES
FOR RESEARCH AND DEVELOPMENT

NICOL H. SMITH, DIRECTOR

FERROMAGNETIC MULTI-DOMAIN PARTICLES

BY

HENRI AMAR [1]

In the rapidly expanding field of ferromagnetic fine powders, The Magnetic Group of the Solid State Physics Division of The Franklin Institute Laboratories has been taking an active part.[2] Experimental and theoretical investigations have been focused on single domain particles because they have the most remarkable magnetic properties (in particular, high coercive force and remanence). However, it seems rather difficult to obtain an aggregate made exclusively of single domain particles. Slightly larger particles (two or three domain) always occur, and the behavior of these multi-domain particles must be investigated. The multi-domain problem is more complex than that of the single domain, and one must resort to simplifying assumptions and approximations. It is the purpose of this note to indicate some of the progress accomplished on the theoretical investigation of these particles.

The first result is that the width and energy of domain walls assume, in these particles, values substantially different from the bulk values. This has been shown in a preliminary study.[3] Demagnetization, which plays little role in large ferromagnetic samples (in the absence of a field), becomes of major importance in these very small particles. A more systematic theoretical study has been undertaken.[4] A two-domain iron parallelopiped with edges parallel to the easy axes of magnetization has been considered. The total energy (exchange, anisotropy and magnetostatic) has been calculated as a function of the wall width. Calculations have been carried through for a cubic particle. The curves in Fig. 1 show the energy per unit volume *versus* the wall width in Angstroms, for various values of the size parameter a (cube edge). All these curves exhibit a minimum $e_{min}(a)$ for a certain value $y_{min}(a)$ of the wall width. However for $a < 200$Å, $e_{min} > e_s = 1.0472$, e_s corresponding to the energy of the cube uniformly magnetized. Thus for $a < 200$Å the two domain configuration is energetically unfavorable and this is in fair agreement with current single domain criteria. For $a > 200$Å, the wall width is much smaller than its bulk value (~ 1000Å)

[1] Senior Research Physicist, Solid State Physics Division.

[2] Papers presented by FIL members to the October 1956 Boston Conference on Magnetism and Magnetic Materials (published by *AIEE*, Feb. 1957 and Note in the JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 262, p. 405 (1956).

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[4] H. AMAR, Nov. 1957, Washington Conference on Magnetics and Magnetic Material, to be published in special issue of *J. App. Phys.* in 1958.

and the wall energy is higher. The size dependence of these two wall characteristics can be seen at a glance in Fig. 1.

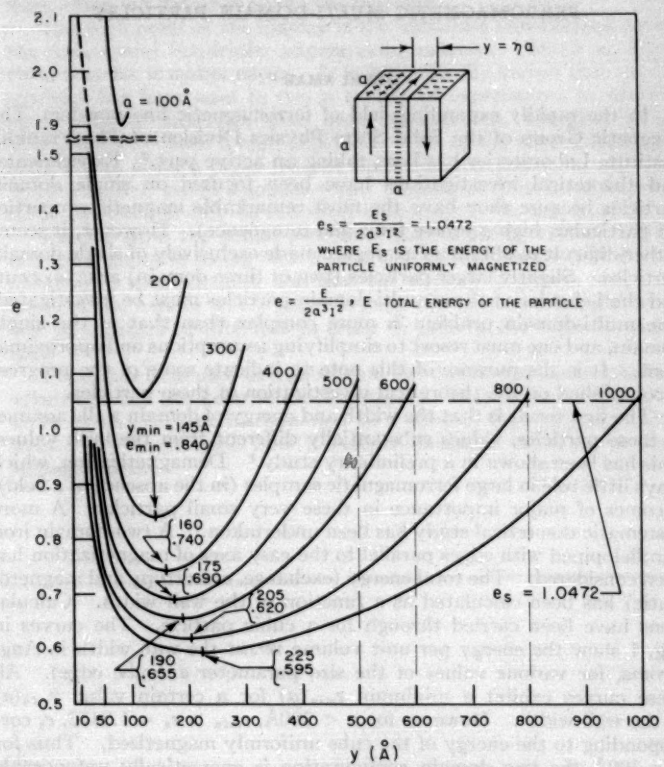

FIG. 1. Reduced energy ϵ per unit volume of a cubic two-domain particle as a function of the wall width $y(=\eta)$ for various values of the size parameter.

The investigation of the dynamic problem of wall motion is currently under way, and will help in understanding the magnetization mechanism of these multi-domain particles. Preliminary calculations already suggest another departure from the familiar ideas on bulk material, namely that wall motion is not necessarily an easy process of magnetization.

THE BARTOL RESEARCH FOUNDATION
W. F. G. SWANN, DIRECTOR

DIRECT OBSERVATION OF PERIODIC VARIATION OF PRIMARY COSMIC-RAY INTENSITY *

BY

M. A. POMERANTZ, S. P. AGARWAL AND V. R. POTNIS

Although the time variations of the cosmic-ray intensity have been investigated extensively (1),[1] the observations of periodicities have generally been limited to measurements of secondary particles by ground-based instruments. Thus, Forbush (2) first noted the existence of an inverse relationship between cosmic-ray intensity and solar activity on the basis of continuous shielded ionization chamber records extending over almost two decades.

Balloon-flight measurements of the total ionization at high altitudes by Neher and Stern (3) appeared to provide an independent confirmation of this effect. Meyer and Simpson (4) detected similar changes with neutron intensity monitors carried aboard aircraft. However, Winckler and Anderson (5) have recently demonstrated that measurements of the type reported in the present note do not show an anti-correlation with the sunspot number indices.

During the current period of maximum solar activity, the phenomenon has been observed with balloon-borne instruments by Winckler (6) and by the present authors. It is the purpose of this brief note to report that, for the first time, an observation of a periodic variation has been made with balloon-borne instruments which directly detect the incident primary cosmic-rays near the "top of the atmosphere."

In an extensive series of balloon flights (7) conducted during the period 1949–1952 when the general level of solar activity was decreasing toward the minimum, no changes in the primary intensity, as measured with quadruple-coincidence counter trains containing 7.5 cm. of interposed Pb, were observed (except for certain *increases* (8) on rare instances associated with specific outstanding solar disturbances). Flights with identical apparatus sent aloft as part of the International Geophysical Year program have now revealed a drastic change in this situation, and the previous day-to-day constancy (with the aforementioned rare exceptions) does not prevail at the present maximum phase of the solar cycle.

During the interval 11 July–29 October 1957, a large number of balloon flights has revealed that, in fact, the primary intensity sometimes decreases to as much as 25 per cent below the normal rate es-

* Assisted by the joint program of the ONR and the AEC, and by the U. S. National Committee for the IGY through the National Science Foundation. Field operations sponsored by the National Geographic Society. Reprinted from *Phys. Rev.*, January 1, 1950.

[1] The boldface numbers in parentheses refer to the references appended to this article.

tablished by the earlier experiments. Within the resolution of the apparatus, no changes in counting rate are detectable at altitudes below 60,000 ft. At the highest altitudes attained, the intensity varies between the maximum (normal, as defined above) and minimum values. Preliminary analysis of the data indicates the existence of a 27-day recurring period which has thus far been followed through four cycles. Presumably, this variation is associated with a solar phenomenon, characterized by this period, which introduces a modulating effect upon the primary cosmic-ray flux. A detailed discussion of these results will be published later.

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BOOK REVIEWS

CONNECTIVE TISSUE IN HEALTH AND DISEASE, edited by G. Asboe-Hansen. 321 pages, illustrations, 6¼ × 9¼ in. Copenhagen, Ejnar Munksgaard; New York, Philosophical Library; 1954 & 1957. Price, $15.00.

The contributors to this book include the pioneers of modern connective tissue research. The result is a most important one-volume review of the many facets of this research. It demonstrates how—as Asboe-Hansen says in the introduction—"To-day, a collaboration between the clinicians and their colleagues in the laboratories is a matter of course. Laboratories are built in conjunction with clinical departments. Clinicians are at work in the laboratories."

Contributions cover such aspects as: the morphology and morphogenesis, the histochemistry and chemistry, the metabolism, the aging of connective tissue; the spreading factor, the inhibition of hyaluronidase, hormonal influence on connective tissue and on infection; connective tissue in wound healing and infection; the pathology of connective tissue, general considerations on collagen diseases, arthritis, certain dermatological conditions, mesenchymal aspects in ophthalmology, fibroses due to injury; observations on arteriosclerosis; connective tissue and cancer; cortisone, ascorbic acid and changes in the reticulo-endothelial system.

There is no doubt that a review of this sort will be welcomed by members of the medical profession of varied qualifications and interests.

There is of course especially much for the tissue pathologist. Klemperer in a most elucidating chapter clarifies the original purport of the term collagen diseases, which collected clinically heterogeneous morbid states into a group because they had in common the seat and features of a basic change of morphology. "In contrast to preceding theories the term did not attempt to explain the implication of the connective tissue."

Altshuler and Angevine stress the pathogenesis of some of the more general reactions as they occur in connective tissue. The reader is brought up to date (1953) with this aspect in a critical review.

The review by McManus covers the methods most used in the study of histochemistry of connective tissue. It also points at some large deficiencies in our knowledge of the histochemistry of the mesenchyme, including enzymatic activities, the lipids and comparative data obtained by carefully controlled studies.

The large amount of attention at present paid to connective tissue and its reactive states, is indeed well demonstrated by this volume. It should be of value to laboratory workers and clinicians with an interest, however, in connective tissue.

GERRIT BRAS
University College of the West Indies

NUCLEAR CHEMICAL ENGINEERING, by Manson Benedict and Thomas H. Pigford. 594 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $9.50.

The field of nuclear engineering has been expanding rapidly and improvements on the old methods and the achievements of the new are frequent. In such a time, it is rather difficult to write a text which will cover the subject matter thoroughly and also keep the material up to date. The authors should be congratulated on the achievement of such a difficult task. This book is one of a very few, if not the only text that is comprehensive on the chemical engineering aspect of nuclear technology. Again, the authors should be applauded for this very timely publication. Timely because, the interdependence of the fabrication of fuel, the reactor operation, and the fuel reprocessing for an economical reactor fuel cycle has never been more acutely recognized among engineers than in recent times. Understanding of the basic elements of reactor theory, fuel processing and fabrication, and the fuel cycle is an essential requirement of engineers in the field in order that optimum coordination among them be achieved.

This text is well organized and clearly written which makes it comparatively easy to read and even the engineers in other than the chemical engineering field will find this text very comprehensive. The role of chemical

engineering in nuclear power is briefly discussed in Chapter 1. Chapter 2 covers the essentials of the nuclear reactions needed for following subsequent chapters. However, it might be recommended that readers get a little more familiar with the reactor theory in another text on the subject, before getting into Chapter 3, which is a very informative and important chapter in the book. It covers material on the comparison of batch and continuous cycles of fuel irradiation, neutron balance, fuel consumption, and reactivity changes. In Chapters 4 & 5, the chemical properties and the processing of more important reactor materials, i.e., uranium, zirconium, thorium, and beryllium are described in fair detail. The authors take the trouble to point out sources of information for further details at the end of each description besides that contained in the references. Chapter 6 describes the solvent extraction of metals which is becoming more and more important in recent time, because of its increasingly wider application. Chapters 7 & 8 cover the properties of irradiated fuel and separation or reactor products. The remaining four chapters deal with isotope separations in detail. Theory involved is presented clearly, then authors incorporate it with recent practices of industry. Rather complete table of properties of the Nuclides is included in the Appendix and it is very useful.

CHANG-KYO KIM
The Franklin Institute Laboratories

SOLID STATE PHYSICS, VOL. IV: ADVANCES IN RESEARCH AND APPLICATIONS, by Frederick Seitz and David Turnbull. 540 pages, diagrams, 6 × 9 in. New York, Academic Press, Inc., 1957. Price, $12.00.

This is the fourth volume of the Solid State Physics Series edited by F. Seitz and D. Turnbull. In the first paper, a 200-page monograph, W. Kanzig gives a systematic and up-to-date expose of the Physics of "Ferroelectrics and Antiferroelectrics." A thorough description of the experimental facts is followed by a study of the optical and thermodynamic properties and domain structure of both ferroelectric and antiferroelectric materials. It is a competent and very well organized presentation of this new and rapidly expanding subject. To be commended: the unusually well prepared and detailed table of contents. In the second paper, F. J. Blatt gives an excellent survey of the theory of electron mobility in solids. Although several other surveys on this subject have been published in recent years, the reader will read with profit: (1) Blatt's discussion of the solution of Boltzmann equation for non-spherical energy surfaces, (2) his analysis of the various scattering mechanisms. The third essay written by T. O. Woodruff deals with the O P W (orthogonalized plane wave) method for the calculation of the Band Structure of Solids. This method has been recently successful in the hands of F. Herman and T. O. Woodruff. This essay is an essential complement to John Reitz's general article in the first volume of SSP.

The fourth contribution is a Bibliography of Atomic Wave Functions by R. F. Knox. It is an up-to-date reference list, using Hartree's notation, and it will prove extremely useful for all workers in the field. This bibliography would have been enhanced by a discussion of: (1) the approximate wave function proposed, e.g., by Slater of Lowden, (2) the role of exchange and relativistic corrections in heavy atoms, (3) the use of the atomic wave functions in Band Structure calculations. The last hundred pages are devoted to the techniques of zone melting and crystal growing. The author, W. C. Pfann (undoubtedly the most important contributor to this field) exposes the principles and the experimental methods with clarity. His report will be greatly appreciated by all physicists and metallurgists engaged in this field of research. In conclusion we may say without reservation that the fourth volume of Solid State Physics is an outstanding member of the series.

HENRI AMAR
The Franklin Institute Laboratories

EXPOXY RESINS, by Henry Lee and Kris Neville. 305 pages, illustrations, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $8.00.

Epoxy Resins, their Applications and Technology is a thorough and highly informative text designed for the user of epoxy resins.

The authors have presented the technology of this resin so clearly that the reader who has but a basic knowledge of chemistry can appreciate the theoretical discussions on topics such as mechanisms of cure and chemistry of synthesis. For the person solely interested

in everyday applications, many data are provided on the physical, chemical, mechanical, and electrical properties. The correlation is shown between these properties and the effects of various curing agents on performance.

Several chapters have been devoted to the different uses of epoxy resins in adhesives, laminates, castings, sealants, encapsulations, and coatings. Besides having supplied sample formulations for each use, the authors have discussed the various ramifications encountered in application techniques. The general quality of this book is exemplified in the chapter on Plasticizers and Flexibilizers. Herein they make the distinction between the two types of compounds and show how various materials are used in these capacities and their effects on performance.

Wisely enough, the authors have included a chapter on a topic which is becoming more and more prominent, "Handling Methods and Safety Precautions."

MARVIN PACKER
The Franklin Institute Laboratories

SYNTHESIS OF PASSIVE NETWORKS, by Ernst A. Guillemin. 741 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1957. Price, $15.00.

MIT's Professor Ernst Guillemin is in all likelihood the world's leading authority on network synthesis. As he puts it, he has "spent practically a lifetime in electric circuit theory, mostly puttering around in a very restricted area defined by the five adjectives: lumped, linear, finite, passive, and bilateral—". He also points out that during this long period he did not once feel the subject was reaching a state where new ideas and things to do were becoming scarce.

This view is apparent in his books which now number five and are all major works. In each of these the keynote is thoroughness and a treatment aimed at giving the student a deep understanding of circuit theory. All of the books are essentially chapters in a long story which sets forth circuit theory and the mathematics of circuit analysis and synthesis.

The present volume assumes complete familiarity with the preceding two, "The Mathematics of Circuit Analysis" and "Introduction to Circuit Theory." In this volume Professor Guillemin feels he is finally getting down to the fundamental theory and methods of synthesis. Even here he has found the subject so extensive that he has had to eliminate all material on applications except for the barest examples. He intends to take up special applications in a later volume.

To appreciate the implications of synthesis as contrasted with analysis one should realize that in the former a solution to a stated problem does not necessarily exist. Moreover, when a solution does exist, it is not unique, there being theoretically an infinite number of circuits having the same response. Thus, in a synthesis problem one is first concerned with the introduction of necessary conditions, and these may be expressed in a variety of forms. The data describing excitation and response may be in terms of time or frequency functions, expressed either graphically or analytically, or combinations of these.

The synthesis of driving-point impedances and the problem of finding network realizations which satisfy these impedances and the imposed conditions constitute the main endeavors of this volume. Realization in the case where the impedance is simply a constant times a variable is obvious; but in the case where more complex functions represent the network, recognition by inspection is no longer possible. It is to this problem of specifying methods for splitting off recognizable parts and operating upon the remainder so that a valid realization is developed that the author addresses himself. This is a fascinating and even astonishing subject, treated in great detail and with Professor Guillemin's characteristic enthusiasm.

C. W. HARGENS
The Franklin Institute Laboratories

PRACTICAL ASTRONOMY, by W. Schroeder. 206 pages, illustrations, 6 × 8¼ in. New York, Philosophical Library, 1957. Price, $6.00.

It is refreshing to run across a book which can be recommended for the beginner which will give the basic fundamentals of astronomy without the necessity of a mathematical background. Such a book is *Practical Astronomy*.

It deals with the many facets of practical astronomy. The first few chapters treat the constellations, the positions of stars and how they can be used to tell time. Astronomy also involves coordinate systems. The familiar one is the altitude-azimuth one. In astronomy right ascension and declination are

used together with sidereal time and hour angle for position determination.

In discussing time an elegant section on sundials is included which permits the construction of these time devices. One of the most satisfactory projects this reviewer knows is the construction and use of a sundial.

Several interesting chapters are presented on planets and their orbits, the Moon and our astronomical calendar with steps given to compute and represent an eclipse of the Moon. The final section deals with the telescope, observing with the telescope and finally a rundown on some interesting objects in the sky.

Practical Astronomy is highly recommended for the beginner.

I. M. LEVITT
Franklin Institute's Fels Planetarium

NUCLEAR ENGINEERING, edited by Charles F. Bonilla. 850 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $12.50.

This excellent reference book impresses on the reader the broad scope of the nuclear engineering field and the many engineering skills essential for designing a nuclear power plant.

Twelve associates of the editor at Columbia University combined their talents to write the text chapters. Each chapter explains concisely the fundamentals of the particular field, and the basic considerations in applying these fundamentals to reactor design.

The topics covered are: "Nuclear Particles and Physics," by William H. Havens, Jr.; "Particle Detection," by Chien-Shiung Wu; "Radiation Protection," by Gioacchino Failla; "Reactor Physics," by R. Wayne Houston; "Shielding," by David Peaslee; "Flow of Fluids and Heat Removal," by Charles Bonilla; "Metallurgy of Uranium," by George L. Kehl; "Thermal Stress Analysis," by Alfred M. Freudenthal; "Instrumentation and Control," by John W. Hoopes, Jr.; "Power Generation," by Theodore Baumeister; "Nuclear Reactor Types," by John W. Landis; and Legal Aspects," by John G. Palfrey.

Considering that the subject of reactor physics is generally treated in a whole book, its essentials from elementary diffusion theory to perturbation theory are quite satisfactorily condensed in one chapter.

Many of the topics included in the chapters on heat transfer, fluid flow, and stress analysis have never before been treated in such detail in a basic nuclear text. The heat transfer, fluid flow, and stress analysis chapters include the basic principles, practical formulas, tables, and graphs for such topics as streamline and turbulent flow, free and forced convection, coolants, steady and transient reactor conditions, boiling, orifices, pumping, slurries, and elastic and inelastic stresses. Because of the wealth of their pertinent information, these chapters by themselves could profitably be used as a reference book.

By studying this book, the engineer will obtain an insight into different design procedures such as optimizing the reactor core to evaluating reactor power plants. For more specialized information, the engineer may take advantage of the extensive bibliographies at the end of each chapter. A specialist in one field will learn the similarity and interplay of the different phases of nuclear engineering, and see how the same numerical and electrical analogue techniques for solving difficult mathematical problems can be applied to many fields.

Since this book will undoubtedly be used by engineers in different fields, it is important to point out that a person totally unacquainted with one of the major topics would most likely require explanations more elementary than those in the text. A specialist acquainted only with reactor physics probably would not comprehend the servomechanism theory in the excellent instrumentation chapter, nor be able to make effective heat-balance calculations for nuclear power-plant cycles. Obviously, it is impossible to include all the fundamentals and also specific design information for so many different specialties in one compact volume. The editor deserves to be commended for his selection and correlation of topics.

An interesting phenomenon occurred in evaluating *Nuclear Engineering*. Most engineers consulted usually expressed their greatest approval for the chapter in their specialty.

Designing a reactor requires engineers who know the specific applications of their field to reactor power plant design, and who also have a broad background of other pertinent reactor specialities. In fulfilling these two goals, *Nuclear Engineering* will definitely serve as a useful reference.

MUSA HALEV
The Franklin Institute Laboratories

BOOK NOTES

DANGEROUS PROPERTIES OF INDUSTRIAL MATERIALS, by N. Irving Sax. 1467 pages, 7 × 10 in. New York, Reinhold Publishing Corp., 1957. Price, $22.50.

Sax's new work augments his previous "Handbook of Dangerous Materials," so well received by chemists and engineers required to work with such materials. This present volume is almost twice as large as the previous one, and it covers over 8500 materials. In addition to expanded data on materials covered in the earlier handbook, this work includes a new section on reactor safeguards and the section on radiation hazards has been considerably enlarged. Of interest to medical men will be the new sections on industrial toxicology and on allergic diseases in industry. Because of the incredible number of materials described, repetitive explanations, warnings, etc. have been eliminated by use of an ingenious system of cross-referencing. Good bibliographies are provided for those who wish to go into a particular subject more thoroughly.

A helpful "Index to Synonyms" makes it easier to use the chemical section. This volume should be in the library of every company manufacturing, shipping, using or marketing dangerous materials.

PRINCIPLES OF THE PROPERTIES OF MATERIALS, by Jacob Porter Frankel. 228 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $6.00.

A different approach to the old problem of properties of materials has been tried in this new text. Rather than concentrating on the various materials (which are apt to "go in and out of fashion"), the author has emphasized the principles and properties. This method requires a slower pace and more outside reading, but in the long run, the author believes it will enable the student to adjust himself more quickly to engineering practice after graduation. The prerequisites for the course are one course in general inorganic chemistry, a knowledge of the elements of atomic theory, calculus, and a course in mechanics.

CONCISE GUIDE TO PLASTICS, by Herbert R. Simonds. 318 pages, illustrations, 6 × 9 in. New York, Reinhold Publishing Corp., 1957. Price, $6.95.

Intended as a guide to newcomers in the plastics field and to interested laymen, this book presents a broad picture of the complex plastics industry, omitting much detail—there are other books covering the subject from a more technical point of view. It describes plastics in general, gives the properties of commercial plastics, their forms, production records, applications, methods of manufacture, and closes with a chapter on "The Future of Plastics." Well written and interestingly illustrated, the book should serve the purpose for which it was intended.

QUANTUM MECHANICS, by F. Mandl. Second edition, 267 pages, 6 × 9¼ in. New York, Academic Press, Inc., 1957. Price, $6.50.

This outstanding text on quantum mechanics, originally published in 1954, has now been revised to include a section on partial wave analysis in scattering theory and a new chapter on the Dirac equation. The student, in addition to the prerequisites for the first edition text, will now need to have some knowledge of the special theory of relativity, in order to understand the material in the new chapter.

AN INTRODUCTION TO PROBABILITY THEORY AND ITS APPLICATIONS. Volume 1, by William Feller. Second edition, 461 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1957. Price, $10.75.

Although the first edition of this rigorous treatise on probability theory appeared a short seven years ago, the author has enlarged upon that original presentation in this revised edition. New material has been added to many of the sections and two entirely new chapters have been added—one on random walks and general fluctuation theory and the other on compound distributions and branch-

ing processes. This first volume of the revised edition has been restricted to discrete sample spaces in order to allow the author to discuss typical problems in detail.

HANDBOOK OF CHEMICAL DATA, edited by R. W. Atack. 629 pages, tables, 4 × 6 in. New York, Reinhold Publishing Corp., 1957. Price, $6.75.

To the chemist who likes to carry his "facts" around—or whose job does not offer easy access to a reference library—this compact handbook should be a blessing. It contains tables of physical constants and properties, and is of a size convenient for slipping into a pocket. In addition to the tables of physico-chemical constants, the book includes tables of atomic weights, solubilities, refractive index liquids, properties of minerals, inorganic and organic compounds, qualitative analysis, volumetric analysis, quantitative analysis, conversion and interconversion, hydrometric tables, log tables, powers of numbers, sines and tangents, mensuration formulas and mechanical constants. This handbook should prove to be a "best-seller" for busy chemists.

THE FOCAL ENCYCLOPEDIA OF PHOTOGRAPHY. 1298 pages, plates, 6¼ × 9½ in. New York, The Macmillan Co., 1957. Price, $20.00.

Issued by Focal Press Ltd., of London, this new encyclopedia of photography covers all phases of the art, from definition of terms through the rules for getting good results with all types of subjects. Twenty-three chapters divide the broad field of photography into separate units, for example, aerial photography, color, developing and processing, flash, portraits, tricks, etc. Written by experts in easily understood language, and amply illustrated with diagrams and reproductions of actual photographs, this encyclopedia will be of use to professionals and amateurs alike.

ESSENTIALS OF TELEVISION, by Morris Slurzberg, William Osterheld and Elmo Voegtlin. 687 pages, illustrations, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $8.50.

Written for the television serviceman, this guide begins with the history of television and then proceeds to describe in detail the various components of the black-and-white and color television sets. Circuit analysis is emphasized and there are many diagrams to aid the reader in following the text.

MARINE ELECTRICAL PRACTICE, by G. O. Watson. 325 pages, illustrations, 5½ × 8½ in. New York, Philosophical Library, 1957. Price, $12.00.

This English book was prepared (by the Chairman of the I.E.E. Committee on Regulations for Electrical Equipment of Ships) as a practical help to marine engineers, to those studying for the Ministry of Transport examinations, and to electricians and operating engineers on ships. The chief concern is not with design, but with performance of electrical apparatus such as generators, switchgear, motors, batteries, cables, steering gear, etc. Although the book is based on British practice, the broad principles will apply to apparatus of other countries.

IONIZATION AND BREAKDOWN IN GASES, by F. Llewellyn-Jones. Methuen's Monographs on Physical Subjects. 176 pages, diagrams, 5 × 7½ in. New York, John Wiley & Sons, Inc.; London, Methuen & Co., Ltd.; 1957. Price, $3.50.

In line with other Methuen Monographs, this one covers briefly but clearly and accurately the basic principles underlying the electrical breakdown of gases. It is aimed at the postgraduate and honors-degree students. Nine chapters include an introduction describing the breakdown phenomena, an account of the dynamical theory of the motion of charged particles, a description of the fundamental gas and electrode processes, five chapters on breakdown under specific conditions, and one chapter on the temporal growth of ionization. The bibliography of over 300 references forms a valuable part of the monograph.

ORGANIC SYNTHESES, Vol. 37, edited by James Cason. 109 pages, 5¾ × 9 in. New York, John Wiley & Sons, Inc., 1957. Price, $4.00.

The latest volume in this invaluable series covers twenty-nine preparations listed alpha-

betically by the common names of the compounds (from Benzofurazan oxide to Trichloromethylphosphonyl dichloride). The presentation follows the style of the previous volume.

GAS DYNAMICS, by Klaus Oswatitsch, translated by Gustav Kuerti. 610 pages, diagrams, 6 × 9 in. New York, Academic Press, Inc., 1956. Price, $12.00.

This English version of a 1952 German work has been prepared by Gustav Kuerti of Case Institute and was supported by U. S. Navy Bureau of Ordnance funds. It encompasses a thorough treatment of the physical and technical problems of gas dynamics, from the thermodynamics of the individual gas particle through steady and unsteady flow, supersonic, transonic and subsonic flow, viscous flow and inviscid flow, to a final chapter on experimental techniques and flow analogies. In the discussion of boundary-layer theory, semi-empirical theories of turbulence have been omitted. In the English version, the literature references have been brought up-to-date.

TRANSISTOR A. F. AMPLIFIERS, by D. D. Jones and R. A. Hilbourne. 152 pages, diagrams, 6 × 9 in. London, Iliffe & Sons Ltd.; New York, Philosophical Library; 1957. Price, $6.00.

This is a brief book on transistor audio amplifier circuits patterned very much after Richard Shea's book of the same title. However Shea's book is more comprehensive in its analysis of the circuits. Jones and Hilbourne make frequent reference to Shea's earlier work, and one presumes much of the material came from this source.

The circuits which contain example parameters show English transistors which are unfamiliar to American engineers. Only a brief table of constants is given, and no characteristic curves are supplied, so that equivalent American types cannot easily be determined.

On the other hand, in commendation of the little volume one can say, as in the case of most English texts, the presentation is wonderfully clear and a pleasure to read. This is a thoughtfully abridged presentation of transistor audio circuits; hence, a respectable summary of principles and techniques may be had by those who can afford time for only a minimum study of the subject.

PUBLICATIONS RECEIVED

SCREW-THREAD STANDARDS FOR FEDERAL SERVICES 1957. PART I: UNIFIED, AMERICAN, AMERICAN NATIONAL, AND NATIONAL MINIATURE THREADS. 208 pages, tables, 8 × 10½ in. Washington, Government Printing Office, 1957. Price, $1.25 (paper).

EELS. A BIOLOGICAL STUDY, by Leon Bertin. 192 pages, illustrations, 5½ × 8½ in. New York, Philosophical Library, 1957. Price, $7.50.

POISON ON THE LAND, by J. Wentworth Day. 246 pages, 5½ × 8½ in. New York, Philosophical Library, 1957. Price, $6.00.

THE ELEMENTS OF PHYSICS, by Alpheus W. Smith and John Cooper. Sixth edition, 671 pages, illustrations, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $7.50.

CURRENT TOPICS

Signals Bounced from Meteor Trails.—High-frequency radio signals, bounced from meteor trails 60 to 100 miles above the earth, have been used experimentally for the first time to transmit images of printed material over a distance of nearly 1000 miles without relays.

The disclosure came in a report by three RCA Laboratories scientists that special facsimile equipment has performed successfully in preliminary tests of meteor-path propagation between the transmitting station of the National Bureau of Standards at Havana, Illinois, and the RCA Laboratories radio research installation at Riverhead, Long Island, an airline distance of 910 miles.

The novel system was developed for the Cambridge Research Center of the Air Research and Development Command. Because radio reflections from meteor trails were believed to be of importance to the Air Force, the Propagation Laboratory of The Cambridge Research Center had initiated a meteor program in 1953. As a result of this program, Dr. Philip Newman and Dr. Joseph Casey of the Cambridge Center came to the conclusion that it should be possible to make radio transmission of visual material via meteor trails. RCA, at the request of the Air Force, developed special equipment to investigate this possibility. The first trial of this equipment during early autumn met with instant success. However, the meteor trail phenomenon is a complicated one and considerable further research will be required to determine how best to exploit this new capability.

The RCA scientists gave this explanation of meteor trail propagation:

When a meteor enters the thin upper atmosphere of the earth, the high velocity of its passage causes the air particles to break down into positive and negative ions. This trail of ionized air, which may persist during a time interval ranging from one-tenth of a second up to several minutes after the passage of the meteor, acts as a reflector of radio signals which would otherwise radiate out into space. Along a transmission path of the type used in the experimental facsimile system, ionized meteor trails appear on an average of several times a minute to close the circuit between transmitter and receiver.

The research team pointed out that meteor path propagation promises ultimately to increase the versatility of all radio communications by providing a means of sending information at times and over distances for which other means may not be available. It also offers a valuable means of supplementing the overcrowded radio spectrum.

According to the report of the three scientists, the experimental RCA system functions this way:

The material to be transmitted is recorded on 35-mm film, which is scanned to produce a signal in a manner similar to the techniques used in television film transmission. The resulting signal is sent out from the transmitter through a highly directive antenna aimed in the direction of the distant receiver. At the receiver, the signal is picked up by another directive antenna each time it is reflected during the brief life of an ionized

meteor trail, and the information is fed to a cathode-ray tube for display on a viewing screen. In the experimental system, photographic techniques are used to record the image as it appears on the screen.

The research team reported that the scanner and transmitter are run continuously, sending copies of a picture over and over at the rate of two complete scans each second. The receiver is also on continuously with the recording unit in a "standby condition."

"When a passing meteor closes the transmission path, the incoming signal trips the recorder . . . to permit reproduction on the phosphor screen," they said. "The circuit then resets for the next burst."

The report stated that the experimental transmitter produces 20 kilowatts of power at a frequency of 40 megacycles, which is in the very-high-frequency range somewhat below the portion of the frequency spectrum used for commercial VHF television service. It added that the "encouraging results" so far have been achieved during preliminary tests of the new equipment prior to the start of planned research program.

Novel Method of Manufacturing High Pressure Air Ducts.—A machine which will reduce the cost of fabricating air conditioning ducts for use in skyscrapers by as much as 20 per cent has been developed by Carrier Corporation. The new device, which the company has spent a year in perfecting, will be used to manufacture conduit ducts for carrying high pressure air at high velocity.

One man can operate the machine from a small control panel. By manipulation of a few switches and push-buttons, any number of sizes of "pipe" from 3 to 24 in. in diameter can be made automatically. The apparatus makes cylindrical duct from a continuous strip of thin gauge metal. Joining the spirally-wound stock by a series of interlocking seams increases the strength of the tubing as much as five times over conventional round ductwork.

An automatic cut-off saw slices the conduit into desired lengths even as the machine continues to produce. It also requires less setup time than existing equipment. Heretofore, two and three machines have been necessary to produce a full range of sizes. The largest machine of this type is twice the size and ten times as heavy as the new Carrier design.

Cylindrical duct first came into use in the 1930's with the development by Carrier of a practical system for skyscraper air conditioning. High velocity air conduits occupy far less space than conventional low pressure ducts and are applied today in all types of multistory structures. They are also highly suitable for mine and tunnel ventilation, dust and material collection, irrigation and drainage lines.

Pipe in standard diameters of 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 14, 16, 18, 20, 22, and 24 inches can be produced. Zinc-coated steel, aluminum or copper metal strips can be used.

Antique Cameras Wanted.—If you have a camera that's more than 25 years old and is a real curio item, you can get a brand-new Praktina or Praktica camera in exchange for it, from Standard Camera Corporation.

Standard is creating a collection of old and historical cameras for display in its showrooms and for loan to museums, schools and public institutions, to show the long and interesting development of cameras and photography.

If you have a camera that was used,

for example, to take a picture of a famous historical event, it may be of interest to Standard Camera. Or, if it is a good example of camera construction in its time, it is equally interesting.

Send a photograph of your camera, along with a description, and a history, if available, to: Old Camera Collection, Standard Camera Corporation, 319 Fifth Avenue, New York 16, N. Y.

New Family of Light Absorbers.—Modern outdoor living has brought increased emphasis on the use of plastics in all phases of home, industrial and business life. The bright colors demanded of these outdoor products have posed a new problem to the manufacturer; to make products that will withstand the fading, degradation and other damaging effects of sunlight.

Not only are plastics, synthetic fibers, dyes and paints affected by sunlight, but also lacquers, adhesives, polishes and many other products. Villain in the manufacturer's fight to maintain color and product quality is ultraviolet light—radiations in the range of 300–400 millimicrons being the chief offenders.

Increasing attention has therefore been given recently to ultraviolet light absorbers which are formulated into the product and convert these radiations to a more harmless form of energy.

The Dow Chemical Company began investigating the problems of light absorption before 1940. A number of conclusions have emerged from this study.

As might be expected, economic considerations play an important part in the selection of any UV absorber. The degree of protection required will, of course, vary with the application and formulation.

Where only a moderate or less permanent degree of protection is required it may frequently be obtained with a more easily synthesized, and less expensive, material. These findings modify the common belief that UV protection can be obtained only with relatively high cost light absorbers.

Test findings likewise have an important bearing on the choice of an absorber. A fadeometer yields rapid results, but these are often difficult to correlate with results of outdoor exposure. Outdoor exposure with stabilized products varies greatly, depending upon the test location. Arizona is hot and dry and ultraviolet light is intense, while Florida is hot, with moderate moisture, and ultraviolet is less intense. These climatic differences account for different degrees of product deterioration.

Where exposure is carried out under glass, the effects of moisture are minimized, those of heat intensified, and a portion of ultraviolet light filtered out. This combination of factors operates to produce results which may differ markedly from those obtained by direct outdoor exposure.

To get, therefore, a valid picture of the results to be obtained in any application, test conditions should approximate as closely as possible those expected in actual use.

The Dow investigation supports the widely-held belief that the most effective stabilization is linked to the presence, within the light absorber molecule, of at least one hydroxyl and one carbonyl group situated ortho to each other. These groups undergo hydrogen bonding to form a six-membered chelate ring—a configuration possessing exceptionally high resonance stability and greatly increased UV absorptive properties.

Based on these considerations, Dow

is now offering commercially a family of four ultraviolet light absorbers, designed to meet the varying requirements of a wide range of applications. They are: Salol (phenyl salicylate), TBS (tert-butyl phenyl salicylate), HCB (5-chloro-2-hydroxybenzophenone) and DBR (dibenzoylresorcinol).

All four products have been used in commercial quantities in Dow's plastic formulations for many years. Salol, one of the oldest and best-known light absorbers, is commercially available and has been in use since about 1935. A colorless, nearly odorless material, Salol has proved effective in cellulosic, hydrocarbon, ester-type and halogen-containing polymers. The other three are now being marketed for the first time.

TBS, completely odorless in formulations, has been found suitable for use in food-packaging films, Dow uses it in its household Saran Wrap.

HCB is used by Dow in certain saran formulations and is recommended for use in polyvinyl halide formulations. Also, it has successfully been used with aluminum pigments, which indicates its use in metallized plastic products.

DBR is one of the most powerful UV light absorbers known. Also used by Dow in certain saran formulations, it is also highly effective in polyester, cellulosic, halogenated and hydrocarbon-type polymers. "None of the numerous commercially available stabilizers evaluated by us displays as high a resistance to ultraviolet breakdown as DBR," Dow technical personnel have reported after extensive tests.

In some instances, UV absorber combinations—such as Salol-DBR mixtures—may be utilized to obtain good stability at relatively low cost. Other absorber combinations to meet other special needs are possible.

A new booklet entitled "Dow Light Absorbers" contains more detailed information about ultraviolet light, degradation mechanisms, stabilizers, and formulating methods. Copies are available from Technical Service and Development, The Dow Chemical Company, Midland, Mich.

Lightweight Radome Fabric.—The new trend toward lighter fabrics for wearing apparel has been adopted by the Air Force with the development of a new material for the construction of the air-inflated radomes used to protect radar antennas from the elements in Northern locations. The material, developed for the Air Research and Development Command, will provide greater mobility for tactical radar equipment.

Engineers and scientists from ARDC's Rome (N. Y.) Air Development Center used a sandwich-type construction for the new material. Composed of du Pont Dacron with a Hypolon coating, the fabric is one-half the weight of radome materials used in the past. The resultant radome is lighter in weight, will cost less to produce, and is easier to handle when erected and transported.

Greater durability and a longer life expectancy are also anticipated with radomes using the new fabric. This will be an advantage in the locations where maintenance is a problem due to the unattended installations at remote locations along the Early Warning Lines that extend across northern Canada.

High-Frequency Fluorescent Street Lighting.—Results of experiments by the Detroit Public Lighting Commission indicate that the use of high-frequency fluorescent street lighting systems can provide higher operating efficiencies, reduced ballast weight,

less internal heating, and greater light output per luminaire.

Under direction of Harold F. Wall, general superintendent of Detroit PLC, an experimental installation of 15 General Electric Form 206S fluorescent luminaires has been operating for about a year on a specially-designed high-frequency system. Power input frequency of 60 cycles is converted to 360 cycles by two units consisting of magnetic frequency multipliers and a power factor correction unit. General Electric's new ultra-high-output "Power Groove" lamps are used in 6 of the 15 two-lamp, 6-ft, luminaires.

Because of increasing vehicle speeds, Mr. Wall feels there is a pressing need for higher roadway illumination levels. One method of obtaining improved lighting levels, he has decided, is to increase the light output of each lamp. To test his theory, Mr. Wall has had the experimental system installed.

The Detroit tests have already shown that ballast weight can be reduced by as much as 75 per cent by use of the high-frequency system. Moreover, early test results indicate that lamp output can be increased by 13 to 18 per cent at a lamp current of 1.175 amps provided by special series ballasts. Experiments also show that an overall increase in lamp lumens of 10 per cent during summer months and 20 to 23 per cent during winter months can be achieved.

Detroit Public Lighting Commission and the General Electric Company anticipate that further operating experience and test data will contribute to improved design of fluorescent street and highway lighting equipment.

High Precision Vernier Resolver.—An electromagnetic angle transducer of exceptionally high precision, called the vernier resolver, has been developed by G. Kronacher of Bell Telephone Laboratories under an Air Force contract. The resolution of this transducer is better than ± 3 seconds of arc. This is about the same angle as that subtended by a baseball at 3 miles.

Such a resolver has potentially wide applications for visual and automatic angle reading systems as required in the machine shop and military applications. At Bell Laboratories, it has been used in an "angle encoder" which converts a shaft angle to a numerical representation acceptable to a digital computer. The standard deviation of the error of this complete encoder is less than ten seconds of arc.

The vernier resolver is a reluctance type, variable coupling transformer. In the present design, two output voltages are produced which vary in amplitude as the sine and cosine of 27 times the angle through which the rotor is turned. Thus, the equivalent of a standard resolver driven by a 27:1 gear train is obtained. Other ratios are possible.

The unit is of small size and simple construction. All windings are on the stator, leaving the rotor free of sliding contacts.

Models of this resolver are being built by Clifton Precision Products Company, Clifton Heights, Pa.

Permanent Pleats and Knife-Edge Creases in Wool Garments.—Development of a process to produce permanent pleats in all-wool dresses and skirts and permanent knife-sharp creases in men's all-wool trousers which will not come out in the rain, warm soapy water or dry cleaning has been announced from Australia through the Wool Bureau in New York.

The development, long desired by apparel manufacturers and consumers, is described by Max F. Schmitt, president of the Wool Bureau, as a "major break-through in scientific work to add still another advantage to the list of superior characteristics wool has enjoyed as the top quality apparel fiber."

Developed in the Geelong, Victoria, laboratories of the Commonwealth Scientific and Industrial Research Organization, the process, patented in Australia, is known as "SI-RO-SET." It has proved successful in tests in several Australian apparel factories and in actual wear trials and is now being licensed to approved firms in that country.

In the process, the garment is sprayed with a weak chemical solution just before the final pressing. The crease is then fixed by steam pressing for 15 seconds. Completely safe for factory application, the process is described as having "no damaging effects on wool and producing pleats and creases that last indefinitely." Details on arrangements for manufacturers in the United States to use the permanent-pleating process for all-wool fabrics have not yet been received in the United States but are expected soon, the Wool Bureau reported.

Measurement of Deviations in Periodic Structures.—An automatic instrument has been developed at Bell Telephone Laboratories for rapidly measuring and automatically recording very small imperfections in pitch uniformity of repetitive structures. The instrument is presently being used for evaluating traveling-wave tube helices, but it can be used equally well for measuring the pitch uniformity of other periodic structures such as precision screws, grids, and ladder lines.

In this instrument, the output is a pen recording which tells at a glance the deviation of each successive relevant part of the periodic structure from the ideal, the ideal structure being one in which the length of each repeated section is exactly the same as every other. Longitudinal displacements are indicated to an accuracy of one micron (1/25 mil). Complete evaluation of a traveling-wave tube helix can be accomplished in less than 5 minutes, compared to more than two man-days necessary by previously available techniques.

A combination of optical, electronic and mechanical technology is employed. Essential features include (1) an optical grating which provides a very accurate distance scale, (2) an optical system for ascertaining the position of the part to be measured with respect to the chosen scale, and (3) electronic means for analyzing this information and recording it on a strip chart.

The part to be measured is rigidly mounted on a moving platform on which is also mounted the precision optical grating. This grating moves past a similar fixed grating, so that a beam of light is interrupted when the rulings on the two are superimposed. The light beam falls on a photocell where these interruptions produce electrical pulses representing accurate distance increments of 1 micron. Another fixed beam of light and photocell combination produces an output pulse when an element of the periodic structure passes a fixed reference point.

The pulses from the measuring scale and those from the part being measured are fed to an electronic computer which evaluates the deviation from the ideal. This information is

then recorded on a chart in such a manner as to provide a direct reading of the actual deviation of each element.

Satellites Followed with Transparent Earth-Sky Globe.—The Russian Sputniks and the American satellites soon to be launched during the International Geophysical Year can easily be demonstrated to students and public groups by using an inexpensive but scientifically designed earth-sky globe now available from Farquhar Transparent Globes, Philadelphia, Pa.

The moon-following device consists of two transparent Plexiglas* acrylic plastic globes mounted one within the other on the polar axis, with a map of the earth printed on the inner globe and a detailed star map printed on the inside surface of the outer globe. The earth globe is turned by a knob on the axis, and a sun pointer is provided between the two globes to indicate the position of the sun for any particular date.

The earth-sky globe can be marked to show the orbit of the satellites for two different days and the precession of the orbit. Times to look for the baby moon can easily be calculated from these known positions and the rate of precession.

Globe maker Robert Farquhar points out that when students see these orbits and other celestial and navigational figures drawn on the earth-sky globe, their imagination is stimulated and they become interested in other problems involving the shape of the earth and its relationships to the natural and artificial moons, the sun, and the planets.

Establishing the orbit of a satellite on the earth-sky globe is done in three simple steps: 1) The sun pointer is placed at the current date as indicated on the ecliptic circle of the globe; 2) The earth is moved to the time position of a known geographic crossing of the satellite; 3) Using this time-fix, a great circle is drawn through this point on the star globe at the proper angle to the equator.

Farquhar's Earth-Sky Model ST-12 sells for $42.50 complete with base, sun pointer, a set of colored china marking pencils and erasing cotton for drawing and changing the various orbits, and a brochure with detailed instructions for a variety of classroom demonstrations which can be given with the globe.

"Hotshot" Tunnel for Re-entry Problems.—Some of the difficult aerodynamic problems associated with reentry of missiles or aircraft flying "far-hypersonic" speeds into the earth's atmosphere are being investigated for the Air Force in "Tunnel Hotshot" at ARDC'S Arnold Engineering Development Center, Tullahoma, Tenn.

The tunnel has special rapid-response instrumentation developed for the Air Research and Development Command by scientists of ARO, Inc., operating contractor for AEDC. This instrumentation permits conventional model pressure distribution and heat transfer distribution measurements during the test runs which have lasted up to a 25th of a second.

Temperatures over 15,000 degrees F., and speeds from Mach 10 to approximately Mach 20 have been generated in the electrical-arc driven intermittent tunnel during the first test programs for the weapon systems of industry "customers." The first test runs for these "customers" were made early this year.

Test programs for Lockheed, Bell, Ramo-Wooldridge, General Electric, and AVCO have been run in the

* Plexiglas is a product of Rohm & Haas Company, Philadelphia, Pa.

"Hotshot" tunnel, which is part of the Gas Dynamics Facility at AEDC. This facility, one of three major laboratories at AEDC, consists of a series of continuous and intermittent-flow tunnels covering the supersonic, hypersonic, and "far hypersonic" (above Mach 10) speed ranges.

In addition to the extreme Mach numbers, high temperatures and pressures, "Hotshot" provides simulation of the real gas effects of vibrational excitation, dissociation and ionization which are encountered in studying aerodynamics of extremely high-speed aircraft or missiles flying within the earth's atmosphere.

This realistic simulation of actual flight conditions is possible in view of the extremely high temperatures and stagnation pressures generated by the tunnel. These pressures have exceeded 20,000 psi.

The tunnel is driven by discharge of an electrical arc, produced by the release of a current of approximately one million amps, from a capacitor bank. High speed motion pictures record the flow of air over the various models mounted in "Hotshot's" 16-inch diameter test section. Illumination for these films is provided by the air itself, which becomes luminous at the resulting temperatures and pressures.

Like the other advanced wind tunnels and high-altitude engine test cells of the Arnold Engineering Development Center, "Hotshot" is operated for use by various companies of the aviation industry in accelerating development of weapon systems projects.

New Packaging.—A new method of packaging for automatic assembly of electronic components has been introduced by International Resistance Company, of Philadelphia. Termed "Grip Strip" by its IRC designers, the packaging is being used for Type BTS ½ watt Fixed Composition resistors.

This unique concept provides a package which is inexpensive, simply constructed, and easily assembled. An important feature of this method is the elimination of the problems of spilling and the accumulation of excess packaging normally encountered in heavy corrugated packs.

A flexible strip holds the resistors securely in place, equally spaced, and at right angles to the strip. A cutting machine can be used to trim leads on the strip without displacement of the units. Leads cannot be bent when withdrawing the strips from their box. The units cannot be accidentally dislodged by twisting, inversion, etc. However, they may be released at the desired time by simply bending the strip backward.

The Fixed Composition Resistors currently being used in this method of packaging are the type most often used in Radio, TV, Aviation, Aircraft, Guided Missiles, Radar, and other similar applications in the electronics field.

Range of Radio Telescopes Extended by New Amplifier.—A new amplifier which may extend the range of radio telescopes ten times farther out among the galaxies has been developed in the Gordon McKay Laboratory of Applied Science at Harvard University.

This device, which may enable man to "hear" the radiation from hydrogen clouds in galaxies beyond the range of any present instruments, was operated in a laboratory test for the first time on Saturday night, Dec. 7th. Scientists believe that the device will allow detection of signals one one-thou-

sandth as strong as can be observed now.

Its potential applications include certain radar systems as well as the research field of radio astronomy.

The "three-level solid state maser" (for Microwave Amplification by Stimulated Emission of Radiation) was developed by a group of Harvard scientists: Dr. Nicholaas Bloembergen, Dr. J. O. Artman, and Sidney Shapiro.

Professor Thomas Gold, Harvard astronomer and authority on radio astronomy, stated that the Harvard College Observatory hopes to apply the maser to the radio telescope as soon as possible. The job cannot be done immediately, he added, because of the complicated and experimental nature of the device.

Professor Gold predicted the new device, once it is installed, would enable radio telescopes to reach out into the universe as far as, or further than, the best optical instruments. A maser-equipped telescope should provide a test of cosmological theories (such as the theory of the expanding universe) "better than any other present means," he said, and should be able to confirm or deny the existence of hydrogen gas between the galaxies, now only suspected.

The maser is an ingenious device which provides amplification by redistributing the magnetic moments of the electrons inside a crystal. The Harvard maser is not the first one, but it is the first to run successfully in the 21-cm. wavelength band—the frequency of emission from interstellar hydrogen.

The heart of Harvard's maser is a single crystal of potassium cobalticyanide, with an intentionally introduced impurity of one half of one percent of potassium chromicyanide. The crystal, about the size of the last joint of a man's thumb, is kept by a bath of liquid helium at 2°Kelvin, a temperature only slightly above absolute zero.

Electrons of the impurity in three discrete energy levels are used. Amplification is gained by shifting electrons from level to level, within the crystal.

In ordinary circumstances, when an electron falls from a higher level to one below it, it gives off energy at a specific wavelength. When radiation of the same wavelength strikes an electron in the lower level, it kicks the electron back up.

In matter under normal conditions, each energy level has fewer electrons than the level below it. When radiation is applied, more electrons jump upward than downward, but a competing process, known as "relaxation," tends to return the system to equilibrium, sending the electrons back down. The time it takes for such downward jumps to restore equilibrium is known as the "relaxation time."

In the Harvard maser, an applied electromagnetic field pumps the electrons continuously from the lowest to the highest of the three energy levels. By keeping the crystal cold, the "relaxation time" is lengthened, and a maximum number of electrons is kept at the highest level. An incoming impulse of 21 centimeter radiation stimulates emission from the top energy level. Its electrons drop to the middle energy level, emitting 21 centimeter radiation. They give off far more radiation than the incoming trigger signal. The net effect is to amplify greatly the incoming signal.